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Discovery

THE MAGAZINE OF SCIENTIFIC PROGRESS

Editor WILLIAM E. DICK *B.Sc, F.L.S.* *Editorial Office* 244 High Holborn, WC1 *Telephone* Chancery 6518
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THE PROGRESS OF SCIENCE

AMERICAN HYDROGEN BOMB EXPERIMENTS

The announcement of the United States Atomic Energy Commission on November 16, admitting that "experiments contributing to thermo-nuclear weapons research" had been included in the recently concluded series of experiments at Eniwetok, could scarcely have been more non-committal. But its wording was such that it was generally taken as indicating that there must be some substance in the rumours and press reports about a hydrogen bomb explosion which began on November 8, and grew in volume during the following week.

On November 8, the *Los Angeles Examiner* had published the first of these reports, reproducing part of an uncensored letter from one of the crew of a ship in the Eniwetok task force. Within the next few days a spate of letters found its way into print. Nearly all these letters claimed that the explosion was that of a hydrogen bomb, and most of them claimed that one atoll had been completely vaporised. One correspondent included a sketch (which has been reproduced in many journals) which showed how the explosion progressed in a series of three bursts at the end of each of which a mushroom-shaped cloud was formed. The idea was conveyed that immediately following the explosion a ball of fire rushed skyward at immense speed, trailing a flaming stalk which turned greyish as thousands of tons of water followed in its wake. Several miles up, a typical mushroom-type cloud was formed. This continued skyward at a great pace and almost immediately threw out a second cloud about a mile higher up. This was scarcely formed before a third burst of energy threw out yet another cloud overtopping both the others, but connected to them by a thin vaporous stalk. At the same time a great blast of heat was felt by the task force, although they were thirty miles away from the seat of the explosion.

Quite how it came about that these letters were uncensored when America is so critical of other nations' security arrangements remains a puzzle. The official statement about the experiments was certainly, in contradistinction, extremely uninformative. It certainly did not leave behind it any certainty that a hydrogen bomb had been exploded, despite the fact that it stated that experiments relating to the manufacture of a hydrogen bomb had been undertaken at Eniwetok. It is difficult to see why the success of the first hydrogen bomb should not be admitted, unless the explosion described with such a wealth of detail was not in fact that of a hydrogen bomb, but the authorities wanted the world to believe such a bomb had been exploded. Once again we have another example of a statement about an atomic development which has the effect of increasing the cloud of speculation surrounding that development; once again the world is left no better informed after the statement than it was before.

President Truman authorised the undertaking of thermonuclear experiments on January 31, 1950. He did so shortly after the publication by a Washington newspaper of a report that an Austrian physicist, Prof. Hans Thirring, had published calculations for such a bomb in his book *The History of the Atom Bomb*.

The basis of the hydrogen bomb is a fusion process, the joining together of light hydrogen atoms to form a heavier substance, helium, at extremely high temperatures, such as would be produced by the explosion of a uranium bomb. If this change could be brought about, immense energy would be generated. On the assumption that 4 hydrogen atoms are converted into one helium atom (which is a considerable simplification of what would have to be a complex set of nuclear reactions), then energy equivalent to about 180,000 kilowatt hours would be released for every gram of hydrogen so transmuted. The equivalent calculation for the fission of 1 gram of uranium 235 gives an energy release of about 22,500 kilowatt hours.

Hans Thirring's calculations were based on the possibility of using lithium hydride to make a hydrogen bomb, and later guesses have been that tritium, one of the 'heavy hydrogen' isotopes would form the basic explosive material of the bomb. In either case the energy released would be much less than in the full conversion of ordinary hydrogen into helium. On the other hand the greater efficiency of the

fusion reaction over the uranium fission reaction (only a small fraction of the U 235 or plutonium in the earliest bombs actually underwent fission, and the rest contributed nothing to the explosion) would increase the relative power of the H-bomb. Statements of its being a thousand times more powerful are based on the fact that there is no potential critical size limit to the bomb; as the critical size factor does not arise, it could, theoretically, be of any size.

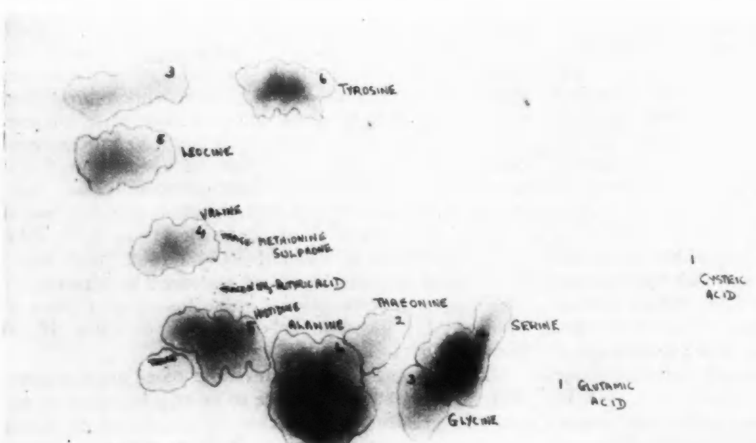
It may well be established later that the first hydrogen bomb was exploded on November 1 at Eniwetok. If that proves to be so, then some very large engineering problems, as for instance those involved in the production of tritium on a large scale, must have been solved, and their solution is no mean technical achievement.

CHROMATOGRAPHY WINS A NOBEL PRIZE

The progress of science depends upon the availability of experimental techniques for the collection of information necessary to test current theories and to formulate new ones. Very often progress is barred simply because there is no method of collecting essential new information or because existing methods are so laborious as to be quite impracticable. It will therefore be appreciated that a new technique which proves exceedingly fruitful, not merely in a specialised branch of research but throughout the whole of one of the major sciences, is of outstanding importance. This distinction may justly be claimed for chromatography, for there is scarcely any branch of chemistry in which it has not already been profitably applied and its possibilities are still very far from being exhausted.

It is therefore no surprise that this year's Nobel Prize for chemistry is awarded for a major contribution to the chromatographic technique. The prize is shared by Dr. A. J. P. Martin, F.R.S., of the National Institute for Medical Research, and Dr. R. L. M. Synge, F.R.S., of the Rowett Research Institute. Their work on paper chromatography is internationally famous and its application has proved remarkably fruitful in the investigation of such diverse and important substances as proteins, carbohydrates, dyes, antibiotics, inorganic salts, hormones, vitamins and drugs. Of these many fields, that of protein analysis, for which Martin and Synge originally devised their method, is perhaps the most outstanding. At the time of their original experiments some ten years ago they were working together in the laboratories of the Wool Industries Research Association, engaged in the analysis of the amino-acids of which wool protein is formed. A counter-current extraction process, in which amino-acids were analysed by their relative capacity to distribute themselves between two immiscible solvents moving in opposite directions, proved unsatisfactory owing to the difficulty in keeping the two solvents quite separate. They therefore hit on the idea of anchoring the aqueous phase by combining it with silica; from water-glass they made a silica gel which, although it had the appearance of a dry powder, contained some 40% of water. Through columns of this they passed mixtures of amino-acid derivatives dissolved in chloroform and found that under suitable conditions the different acids lodged at different levels on the column and could thus be separated. This effect is very similar to that observed when solutions are passed through columns of powdered adsorbents, such as alumina, in conventional adsorption chromatography. Here, however, the separation principle is quite different, depending upon differences in adsorptive affinity and not on differences in distribution between solvents.

Satisfactory though this method with silica gel was, it was not delicate enough to meet the exacting needs of Martin and Synge. They found that the water normally present in absorbent paper, such as filter or blotting paper, could effect separations in the same sort of way as that in silica gel. If strips of such papers were dipped, under suitable conditions, in very dilute solutions of amino-acids in solvents such as phenol or collidine the different acids



Microanalysis of urine by partition chromatography. The various constituents are brought to different points on the paper and identified by means of a colour-reagent. (*Courtesy Dr. C. E. Dent, University College Hospital Medical School.*)

DR. A. J. P. MARTIN, F.R.S.

DR. R. L. M. SYNGE, F.R.S.

moved along the paper at different rates and thus became concentrated at different spots on the strips, and could be located at the end of the experiment by spraying the paper with a reagent such as ninhydrin which reacts with different amino-acids to produce compounds with characteristic colours in such a way that the resultant colour identifies the acid which is concentrated in a particular region of the paper strip. In a later and more ingenious variation of this method they used sheets of paper instead of strips, and, by passing different solvents twice in two directions at right-angles, contrived to spread the acid over the whole sheets. By thus increasing the space available for marshalling the different acids they much increased the selectivity of the method.

Paper partition chromatography owes its value to two principal qualities. First, it is extremely simple, requiring no complex apparatus whatsoever, and so lends itself to making a very large number of simultaneous analyses. Secondly, it is almost unbelievably delicate, being capable of detecting, and if necessary estimating, a few micrograms of individual substances; it is thus ideally suitable for examining substances available only in minute quantities.

Although it is to Martin and Synge that we undoubtedly owe the present intensive and fruitful use of paper chromatography—for the results obtained by them at once commanded wide attention—the method is not by any means a novel one. The fact that the constituents of solution segregate on filter paper was well known at least a century ago, and was experimentally investigated by Runge. He was followed by Schoenbein and, more particularly, by Goppelsroeder. The latter developed an elaborate system of what he termed "capillary analysis", and published a book on the subject which attracted considerable attention at the beginning of this century. These earlier experiments with this type of chromatography gradually dropped into obscurity, probably because problems then awaiting solution did not require the extreme sensitivity which the technique offered, with the result that the men who were investigating those problems preferred to use conventional and well-tried methods that could serve their purposes equally well.

GERMANIUM FROM COAL

Germanium was little more than a specific curiosity until the 'transistor' device was developed, now familiar as the widely used crystal rectifier which can replace the thermionic valve for certain special applications. Both germanium diodes and triodes are now marketed, and their production has necessitated the preparation of germanium of very high purity. The perfecting of a process capable of yielding germanium in quantities sufficient to meet commercial requirements presented some tricky chemical problems, which were in fact solved in a remarkably short time. This point emerges from the informative article by R. C. Chirnside and H. J. Cluley about the extraction of germanium from flue dusts which was recently published in the *G.E.C. Journal*.

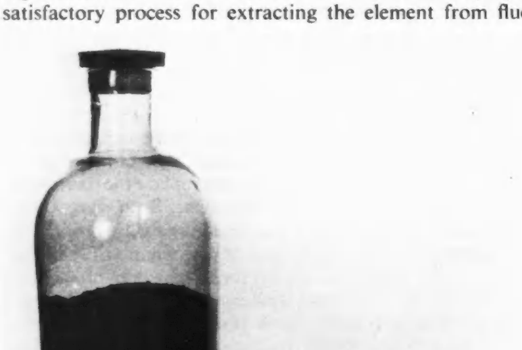
British interest in the germanium present in coal dates back to the mid-1930s, when the late Sir Gilbert Morgan (who was director of the Chemical Research Laboratory at Teddington) and G. R. Davies studied the possibility of extracting the element from coal. (It should be stressed that their interest was very far removed from any thought of commercial application for this rare element.) These two workers discovered that most British coals contained germanium in varying degrees, often of the order of 20 parts per million. However, on ashing the coal in the hope of concentrating it, they found that substantial proportions

of the germanium were lost by volatilisation. Faced with this difficulty, they argued that similar volatilisation of the germanium would be likely to occur on utilisation of the coal in, for example, gas-works, and that the volatilised germanium might be expected to condense in flue dusts deposited in cooler parts of the gas system. This approach appeared promising in that gallium, another rare element occurring in coal, had been shown by H. Ramage to accumulate in certain flue dusts.

Examination of many samples of flue dusts, principally from gas-works, showed that both germanium and gallium were nearly always present, although the concentrations found varied widely. A number of the dusts, however, contained as much as 1% of germanium and similar amounts of gallium and offered a much richer source of these rare elements than could normally be obtained by direct ashing of the coal. Thus this discovery offered the possibility of the production of two rare and costly elements from a waste product, and Morgan and Davies succeeded in evolving a small-scale method for the extraction of germanium and gallium from flue dust.

G.E.C. entered this field of research when it began to require germanium for development work on crystal valves. The G.E.C. Research Laboratories embarked on a survey of the flue dusts with the object of locating rich sources of germanium. (The need to concentrate on the richest flue dusts is obvious when one realises that a dust containing as much as 1% of germanium would yield only about 20 lb. of germanium per ton of dust.)

In parallel with this search for germanium-bearing dusts, experiments were carried out with the aim of developing a satisfactory process for extracting the element from flue



A comparison (*left to right*) of flue dust, germanium tetrachloride liquid, dioxide powder and the pure metal respectively, at various stages of the extraction process.

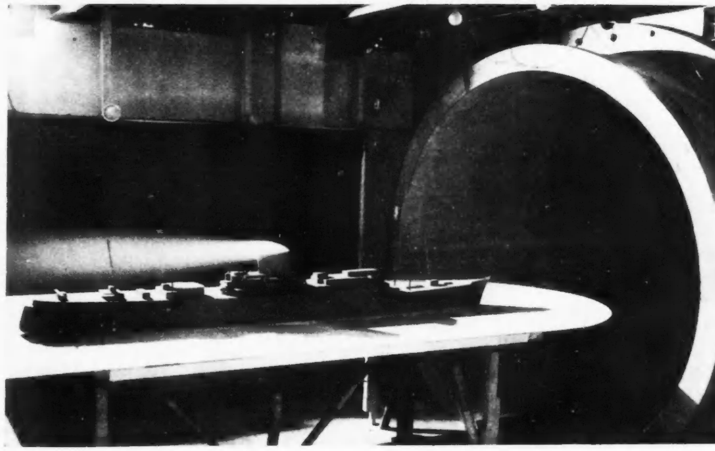
dust. Treatment of the dust with strong hydrochloric acid converts the germanium dioxide into germanium tetrachloride, which boils around 84 C. and can therefore be separated by distillation. But it was soon apparent that this procedure was applicable with success to few dusts; in most cases, only a small fraction of the germanium present could be recovered by this method.

At this stage in the investigation the G.E.C. Research Laboratories joined forces with the research men of Johnson Matthey & Co., the old-established firm which has long specialised in the refining of rare and precious metals. A smelting technique was perfected which yielded a concentrate from which the germanium could be readily extracted. This smelting process is based on the fact that metallic iron will function as a 'collector' for germanium and that when a dust is smelted with reducing agents the iron oxides present are reduced to the metal and form a molten alloy containing those other constituents, such as germanium and arsenic, which are also reduced to the metal under the conditions used. (Gallium does not readily concentrate in the alloy and to recover this element the addition of copper as a 'collector' is necessary.) The smelting operation is carried out in a small reverberatory furnace which will take a 1-ton charge of dust. The product of the smelting is an iron-copper alloy containing usually about 4% of germanium and about 2% of gallium and represents almost complete recovery of these two rare metals from the flue dust.

This alloy is then dissolved by means of a chlorine treatment and the resulting solution is distilled to recover the germanium, the conditions of distillation being controlled so that the distillate separates into two liquid phases. One phase consists of a hydrochloric acid solution containing only a trace of germanium and this is discarded; the other phase is crude liquid germanium tetrachloride and represents the primary product of the extraction process. The gallium can also be recovered by suitable treatment of the solution remaining in the stills after the distillation.

Very pure germanium was needed for the development work on crystal valves. Therefore the germanium tetrachloride derived from the smelting process required considerable purification before it could be used, as it was heavily contaminated with arsenic trichloride. This impurity was almost entirely eliminated by a delicate system of fractional distillation—the purified product contained arsenic to the extent of only a few parts per million as its only detectable impurity. The researchers' target was a material containing not more than 0·5 parts of arsenic per million—which is a much lower limit than that accepted as permissible in many foodstuffs—so they still had a long way to go. They next found, however, that it was possible to remove nearly all of the remaining arsenic by treating the germanium tetrachloride with metallic copper, when the arsenic in solution (as chloride) reacts with the metal, and arsenic is deposited on the copper as an insoluble grey film. (To keep track of the arsenic in the different stages of the purification process the chemists made use of radioactive arsenic, As^{76}, obtained from Harwell.)

The final product contained arsenic to the extent of only 0·05 parts per million, or even less. In 1950 it became possible to start commercial production of germanium of this degree of purity.



Designs for ships' funnels can be tested in this open jet wind tunnel to see that their smoke plumes will stream away from the deck.

WIND TUNNELS AND INDUSTRIAL PROBLEMS

For most people the term 'wind tunnel' immediately suggests the use of this apparatus in the aeronautics field. But problems of air flow arise in connexion with many other things besides aircraft, and it is these other applications which are dealt with in the new publication by the National Physical Laboratory entitled *The Industrial Application of Aerodynamic Techniques*.*

Wind-tunnel tests are advisable before designs for new suspension bridges, for example, are accepted. In fact such testing has been regarded by engineers as an indispensable precaution ever since 1940 when the 2800-ft. span bridge over the Tacoma Narrows in the U.S.A. was rocked to pieces by oscillations set up by a moderate wind. To make sure that no such serious oscillations could arise with the proposed suspension bridge across the Severn, the N.P.L. has done a great many wind-tunnel tests on models. This necessitated the building of a large, temporary, wind tunnel over 150 ft. long, which was specially erected for this particular job. This was housed in a hangar on the disused Thurleigh Airfield near Bedford. Tests with large-scale models of the proposed bridge indicated that the favoured design should be able to stand up to the highest natural winds it would be likely to encounter; even when tested at wind-tunnel speeds corresponding to winds of over 200 miles an hour shaking the full-scale bridge, the models betrayed nothing in the way of potentially dangerous oscillations.

The wind resistance to the motion of cars and railways can also be studied in wind tunnels, to see the way modifications in their shape can reduce that resistance. Experiments made at the N.P.L. with some models of cars showed that there was a tendency for the front wheels to lift at high speeds. This effect, which would affect both the steering control and the wear on the tyres, was studied by the Teddington scientists who showed how to minimise it by modification of the car design. (In this connexion the report states that the scope for reducing wind resistance in the case of cars is necessarily limited, but partial streamlining does lead to a very useful saving of horsepower.) One discovery that has been made during experiments with models of railway trains is that the sealing of the gaps between carriages significantly reduces the aerodynamic resistance in the presence of cross-winds.

What happens to smoke after it leaves a factory chimney, for instance, is another kind of problem which wind tunnels are being used to investigate. One excellent example of this type of work is the series of experiments done at N.P.L. to find the best effective design of ships' funnels to keep decks free of smoke. Another is provided by the Bankside power station project; a power station opposite St. Paul's was a proposition which aroused a great deal of opposition, particularly because of the prospect that a cloud of smoke from its chimney might stream across the river and obscure the cherished London landmark. But by increasing the height of such chimneys it is possible to take advantage of atmospheric turbulence and make sure that any smoke is dispersed so effectively that it no longer constitutes a nuisance. A wind-tunnel study solved the Bankside problem.

The N.P.L. booklet gives a good idea of the large range of applications for various types of wind tunnels. Probably this laboratory has used this apparatus more widely and extensively than any other research institution in the world, for its first wind tunnel was constructed as long ago as 1902 and it has gone on extending its wind-tunnel experiments ever since.

One last example from the booklet brings us back to the realm of aeronautics. The authorities had been worried about the number of aeroplane crashes on the Rock of Gibraltar, and asked the wind-tunnel experts of N.P.L. to investigate.

It was thought that downward-moving streams of air might be the cause, and a small-scale model was tested in winds of different speeds and directions. As a check, balloons were sent up on the Rock itself and the results obtained agreed very closely with the experimental ones. The tests showed that persistent vortices were created by winds. They also showed what precautions should be taken by aircraft flying over Gibraltar according to the weather at the time.

* This is published by H.M. Stationery Office, price 3s. 6d., and forms the second booklet in the N.P.L. series called "Notes on Applied Science".

UNDERGROUND GASIFICATION

L. T. MINCHIN

B.Sc. M.Inst.Gas Eng.

The basic idea of underground gasification is one which has exercised a particular fascination on more adventurous minds for nearly a century. Siemens in 1866, and Mendeléef in 1888, put forward proposals of this kind, and Sir William Ramsay in 1912 again took up the idea and actually planned some practical experiments which, however, he did not live long enough to carry out. It was his belief that the labours of the coal miner might be eliminated by the process; it should be possible, he thought, to turn the coal into gas *in situ* and send it to the surface in pipes. From there it could be distributed to wherever it was needed. It is said that Lenin, in exile during the years before the First World War, was much attracted to the idea, and in consequence of this, work was started on the project in Russia as long ago as 1932. In the West, practical work started taking shape in 1944 (Belgium), in 1947 (U.S.A. and Italy) and 1949 (Morocco and Great Britain).

It is clear nowadays that Sir William Ramsay was over-sanguine, and in fact the process is not likely to result in the abolition of normal mining methods. The ambitions of those who are concerned with developing this process have been narrowed down to a project which is still, nevertheless, very important; namely, the utilisation of seams of coal which are too thin, too dirty or too steeply inclined to be exploitable by ordinary mining. As the amount of coal in this category lying below the surface in Britain may reach 1000 million tons, this remains a very important potential development.

The normal procedure in underground gasification is to start a fire in the seam and to blow air steadily down to feed the underground flames. The aim is not to achieve complete combustion—which would lead to an inert mixture of carbon dioxide and nitrogen—but to burn the coal partially, so that a low-grade gas containing carbon monoxide and perhaps hydrogen (if water enters into the reaction) is produced. The basic reaction is the one normally employed in making 'producer gas', namely:

$$2C + O_2\ (+4N_2) \rightarrow 2CO\ (+4N_2).$$

The coal in this equation is shown as carbon, but, of course, ordinary coals contain hydrogen, oxygen and sulphur as well—in addition to the ash, or incombustible residue. Distilled out of contact with air, coal normally gives rise to coal gas (mostly hydrogen, methane and smaller amounts of other hydrocarbons), coke being left behind; this is the process of 'carbonisation' carried on in ordinary gasworks. If one blows air through a lighted coal seam, both these processes happen at the same time; some of the coal is being burnt to CO and H_2, while adjacent layers are being heated up and are distilling off coal gas—which may, of course, be burnt underground if there is free oxygen to combine with it. A third reaction which takes place is between water vapour and carbon (there is nearly always some water in the coal):

$$C + H_2O \rightarrow CO + H_2.$$

If necessary steam can be pumped down with the air to increase the extent of this reaction.

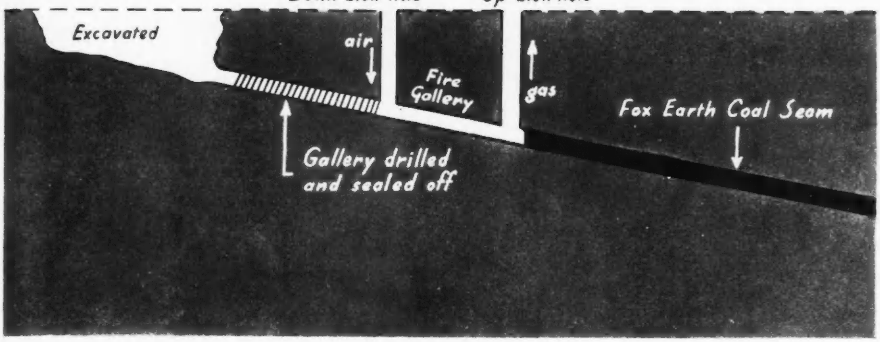
The net effect of these three reactions is that a gas is obtained which, because of the large amount of nitrogen it contains, is very poor in heating value by comparison with ordinary town gas. Town gas normally produces 450 to 500 B.TH.U. (British Thermal Units) per cubic foot when it is burnt; the corresponding figure for underground gasification gas is rarely higher than 100, and often it is as low as 20 or 30 B.TH.U. Much richer gas is obtainable if oxygen (or even oxygen-rich air from some neighbouring chemical plant) can be used in place of air—but it is only rarely that this is practicable. Nevertheless, the poor quality can be compensated by a large quantity, and under ideal conditions 70% of the potential heat in the coal can be brought to the surface.

THE LINKAGE PROBLEM

The early tests of underground gasification made in Russia at the Gorlovka mine used a steeply inclined seam, and operations were conducted from the line along which the seam outcropped to the surface. The basic principle was to construct a huge U by drilling two holes down vertically and then having the bottom of the U constructed by underground workers. After this the coal was ignited and air passed down one leg of the U and up the other until all the coal in the 'panel' between the two legs had been used up.

A similar principle was used in the first British tests at Newman Spinney, near Chesterfield, in 1949, only in this case the 'fire gallery' was not dug but *drilled* in the thickness of the coal-bearing seam (known as the Fox Earth Coal Seam) from an exposed point near the surface, (Figs. 1 and 2). This obviated the need for underground workers, but it proved a very tricky task to keep the drill in the thickness of the seam. Even more difficult was the drilling of the two vertical shafts so that they would intersect the surface. Although this too was eventually achieved by the skilful use of radioactivity and electrical techniques, the necessity for these would clearly be a big disadvantage in the practical operation of the process.

Accordingly, attention has during the last year or two been rather concentrated on other ways of obtaining 'linkage' between the down-blow hole and the up-blow hole. Once a passage of sufficient size has been created which will allow a reasonable quantity of air to pass through, the channel is rapidly enlarged by the combustion of the coal. Ultimately it becomes too large; then some of the air appears unchanged at the up-blow point, and the heating value of the gas falls to a very low figure. At this stage most of the gas that is made is being burnt underground before it ever reaches the surface, and the sensible heat in the gas stream is usually high, even though its calorific value is low. When this stage is reached, attempts are usually made to create a fresh channel through the coal to another borehole.



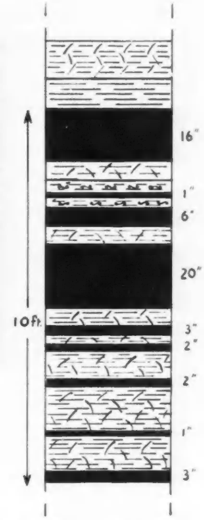


FIG. 1 (*left*). Diagrammatic section showing arrangement for underground gasification of coal seam at Newman Spinney.
FIG. 2 (*right*). Vertical section through the Fox Earth Coal Seam at Newman Spinney. The 'leaves' of coal are shown in black, separated by bands of shale. The seam would not be worth mining by conventional methods, and could only be utilised by underground gasification.

Before gasification of coal can start, however, it is necessary to make some sort of underground passage between the holes, and much ingenuity has been devoted to this end. Attempts have been made to drill hydraulically by jets of water at very high pressure, and in Missouri some quite successful tests have shown the possibility of opening up the underground path by means of high-voltage discharge.

CREATING CHANNELS WITH COMPRESSED AIR

Perhaps the most remarkable method of all—and one which has been developed in this country by the Ministry of Fuel and Power team working near Chesterfield—is that known as the *pneumatic lift*. It has been found possible bodily to lift the overlying strata from the coal seam by applying a fairly high air pressure down one of the holes. Compressed air rushes through the gap thus made, and if the coal is then ignited a channel is begun which ultimately burns through. When that happens the supply of compressed air can be discontinued.

It might be thought that enormously high pressures would be necessary to lift the rocks bodily off the coal seam over a considerable area. Surprisingly enough, it turns out that a pressure of only about 100 lb./sq. in. (i.e. seven atmospheres) is needed for every hundred feet of depth below the surface; this is a calculated figure, but it agrees very well with what was found by experiment. The first tests on this method were made by C. A. Masterman at the Ministry of Fuel site near Chesterfield in 1950. The seam chosen was one lying at 90 ft. below the ground. Air was pumped down at steadily increasing pressure, and the rate of air-flow out of another borehole in the vicinity was measured at each stage. At 75 lb./sq. in. the air-flow out of a borehole 33 ft. away was 150 cu. ft./hr.; when the pressure increased to 120 lb./sq. in. the flow rate went right up to 1200 cu. ft./hr. Even at 4000 cu. ft./hr. the pressure was only 125 lb./sq. in. This very sharp drop in the resistance of the seam corresponded obviously to a widening gap between the strata; the earth was being lifted by the air pressure, and the critical pressure is just what would be expected from the density of the rocks above.

This principle of high-pressure linkage, which is probably Britain's most important contribution to the technique of underground gasification, is likely to prove of the greatest importance. Once the connexion between the two boreholes has been established through the thickness of the seam, a fire must be started at the foot of the high-pressure hole. To maintain the igniting burner alight when the air pressure had risen to 100 lb./sq. in., hydrogen from cylinders had to be used, and the fire thus started spread through the cracks made by the air pressure until a continuous burning channel had been created. Although there are various difficulties not yet completely overcome, this high-pressure linkage system seems altogether more promising than the earlier experiments in which miners had to be used to cut a gallery in the coal. The most recent experiments show that it may be speeded up considerably by the addition of oxygen to the air during the initial stages.

As combustion proceeds in the coal seam, open spaces develop which might cause an unwelcome amount of free air to pass through the zone unchanged. Fortunately this effect is reduced by falls from the roof which usually tend to block up the burnt-out sections and divert the air stream to the burning 'face'. In time, however, the free oxygen in the gases coming up from the seam becomes too high, and a fresh borehole must then be opened up, and a fresh underground linkage made. Development work in Great Britain is now concentrating on the best practical way of methodically working a coal seam; one pattern of development proposed is shown in Fig. 3.

WHAT KIND OF COAL SEAM?

When we speak of the coal reserves of a country we usually have in mind only the coal which can be mined by ordinary methods. To be included in this category a coal seam must not be deeper than 4000 ft., and it must be at least 2 ft. 6 in. thick; the coal in it must be good quality

with not too much sulphur, stones or shale 'partings'. (The last mentioned are the layers of metamorphosed mud which lie between successive layers of coal.)

A glance at Fig. 2 which is a section through the seam used for the first experiments at Newman Spinney, near Chesterfield, shows the make-up of a seam which ranks as 'uneconomic' by ordinary standards, but which can be made to yield valuable fuel by underground gasification. By ordinary mining methods one would have to excavate a great deal of shale to get at this coal; moreover, some of the separate layers themselves are of very poor quality; the coal in the 20-in. layer is 50% 'dirt' and contains 9·3% of sulphur, for example. At the other site, near Bayton, in Worcestershire, where coal is being gasified underground, the sulphur content is also high, and this would constitute a grave objection if the coal were mined in the ordinary way. When subjected to underground gasification, however, it is quite possible that the sulphur can be economically extracted from the hot gases. In view of the present world shortage of sulphur, this may prove an important advantage of the process.

The reader may be tempted to ask how much coal there would be available within a limited area to make these operations worth while. The answer is, that one square mile of coal seam having a total thickness of three feet (which is only two-thirds of the amount shown in Fig. 3) would contain three million tons of coal. Even if it did not prove possible to utilise more than, say, 50% of the total, it is clear that this would result in the utilisation of a very substantial amount of fuel. That amount is, by no means insignificant when compared with the annual production of coal in Britain, which is about 220 million tons.

USES FOR THE GAS

From what we have already said, it will be clear that there is little prospect of the gas produced being of any use for augmenting an ordinary district gas supply. With a calorific value of about one-fifth to one-tenth of ordinary coal gas, the costs of pumping it any distance would be much too high, even if it could be made to burn properly in the customer's appliances. The only exception to this is in the case where oxygen or oxygen-enriched air can be supplied through the down-blow hole; in these circumstances a calorific value of 250–300 B.TH.U./cu. ft. can be obtained, and this is the line of development on which Belgian scientists seem to be working.

Apart from this, however, there are two main possible ways in which underground gasification could be exploited. These are for (*a*) the synthesis of petrol, and (*b*) the generation of electricity. The experimental work in the U.S.A. was begun with the first aim in mind, the Americans being acutely interested in safeguarding their supply of liquid fuels in the remote event of natural petroleum becoming exhausted. It was thought possible that a large-scale process for making motor spirit from otherwise unusable coal might be developed. The general method of synthesising motor spirit from CO and H_2 is usually known as the Fischer-Tropsch process; it depends upon reactions such as the following, showing formation of octane:

$$8CO + 17H_2 \rightarrow C_8H_{18} + 8H_2O + 403{,}000 \text{ calories.}$$

It will be seen from this equation that one needs to have roughly twice as much hydrogen as carbon monoxide. The gases for this synthesis are available in the gas mixture produced by underground gasification but to maintain a gas mixture in which the hydrogen and carbon monoxide are present in the proper ratio would be difficult. Exact control of the composition of the gas mixture would not normally be possible, and in view of this factor the idea of running a Fischer-Tropsch process on the gas mixture obtained from underground gasification seems nowadays to be receding, and the second possibility—electricity generation—appears much more likely to achieve practical results.

Electricity generation is certainly the most likely end of the British experimental work, and indeed the Ministry of Fuel and Power announced in October 1952, that electricity had actually been generated at Bayton and used to provide a certain amount of lighting on the site. It is understood that in this case an ordinary gas engine of the reciprocating type was used, but no doubt the gas turbine would be adopted for full-scale working. The power station would, one presumes, be established at some central point on the area to be exploited, and radiating pipelines would convey the gas to the turbine generators. Fig. 4, a photograph taken at the experimental site at Bayton, gives some idea of how the system would operate; doubtless in actual operation a more tidy development scheme would be possible. As boreholes became useless, the pipes would be removed and reconnected to new holes; presumably the system of hole drilling would be calculated to make the minimum amount of pipe alteration necessary as the working of the area proceeded. It should be possible to restore the land to agriculture quite simply after the coal underneath a given area has been

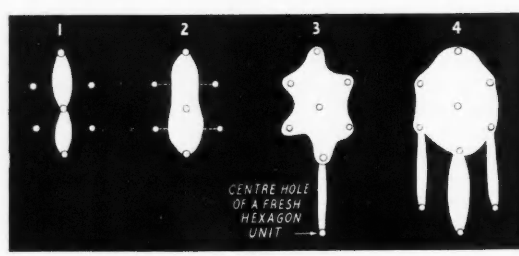


FIG. 3. Plan of one possible pattern of development for an underground gasification scheme, based on arrangement of boreholes in hexagonal units. Four successive stages in the sequence of operations are shown.

1. Gasification is commenced; the coal proceeds to burn away in two cigar-shaped zones, which increase in thickness.
2. It is now necessary to link up the remaining four boreholes in the first hexagonal unit. This is done pneumatically; by compressed air, four channels are created in the seam, along which gasification can proceed.
3. Nearly all the coal inside the hexagon has now been gasified, making it necessary to link up with the next hexagon unit.
4. Linkage has been effected with three boreholes of the second hexagon system; cigar-shaped zones of gasification grow along three of the new channels.

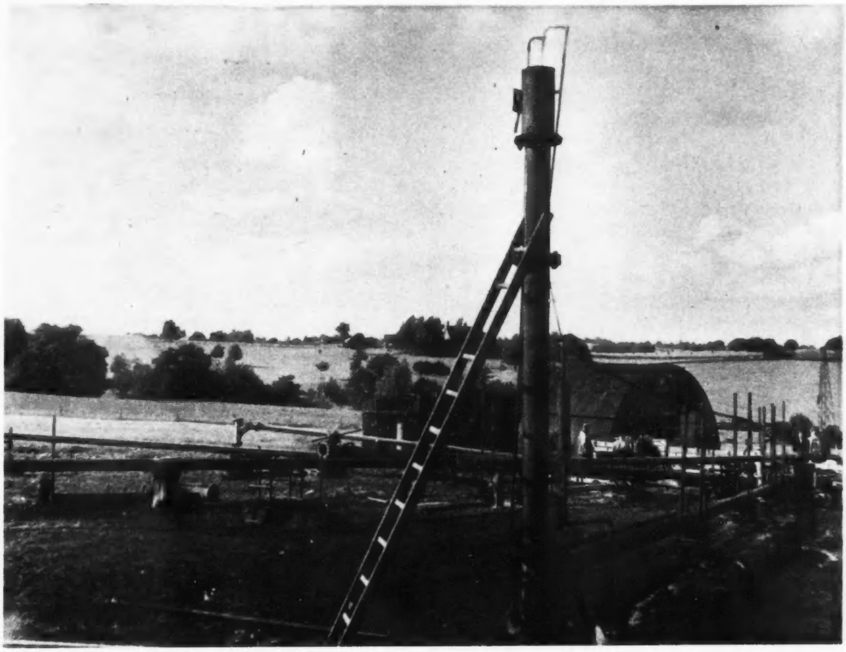


FIG. 4. Underground gasification experiment at Bayton, Worcs. The up-blow pipe is conspicuous in the foreground. When the flow is reversed, air from the horizontal pipe alongside is fed *down* the same borehole.

utilised, though there will probably be a certain amount of land subsidence, especially with shallow seams.

The area enclosed at Bayton is smaller than at Newton Spinney, only seven acres, but there is about 100,000 tons of coal under it in three seams, and this is coal which could not possibly be used economically by ordinary mining processes.

OTHER POSSIBILITIES

There can be no doubt that the process of underground gasification is attracting widespread interest, and the experimental work which is going on actively in this country, in Belgium (in association with Italy, France and Poland) and in the United States will probably bear fruit before long in a practical full-scale or semi-full-scale plant.

One of the most interesting possibilities for the not-so-near future is that electricity may itself be used to carbonise coal underground. Some preliminary experiments have been made on these lines at the Tiger Mine, Hume, Missouri. Here a seam 182 ft. below the surface was worked by three consecutive processes. Firstly, electricity was used to effect the linkage of boreholes; a high potential discharge between electrodes in the coal was used to make the initial connexion between boreholes which could be up to 60 ft. apart. In this way a core of conducting semi-coke was formed between the electrodes. In the second phase, a current passed along this coke core, heated the surrounding coal and carbonised it, producing a rich coal gas with a calorific value of about 650 B.TH.U./cu. ft. When the zone lying between the electrodes had been converted into coke, the third stage began with air being blown through the fissures in the coke, and producer gas being generated as in the more ordinary underground gasification discussed earlier in this article; no electric current is used in this last stage.

From the theoretical point of view this scheme has considerable advantages; not the least being that it enables one to produce a rich gas which could be economically transported by pipe-line. That it is not wildly impracticable is shown by the fact that at Kvantorp in Sweden a somewhat similar process has been in commercial production for some years, only in this case it is oil-bearing shale which is being exploited *in situ* instead of coal. However, electrodes are sunk into the stratum of oil shale and the vaporised oil is drawn up through boreholes. It seems as if the combined experiences of the Kvantorp oil-shale works in Sweden, and the Tiger Mine plant in Missouri may well lead us on the next step forward, after electricity generation from our underground coal resources has become an established fact.

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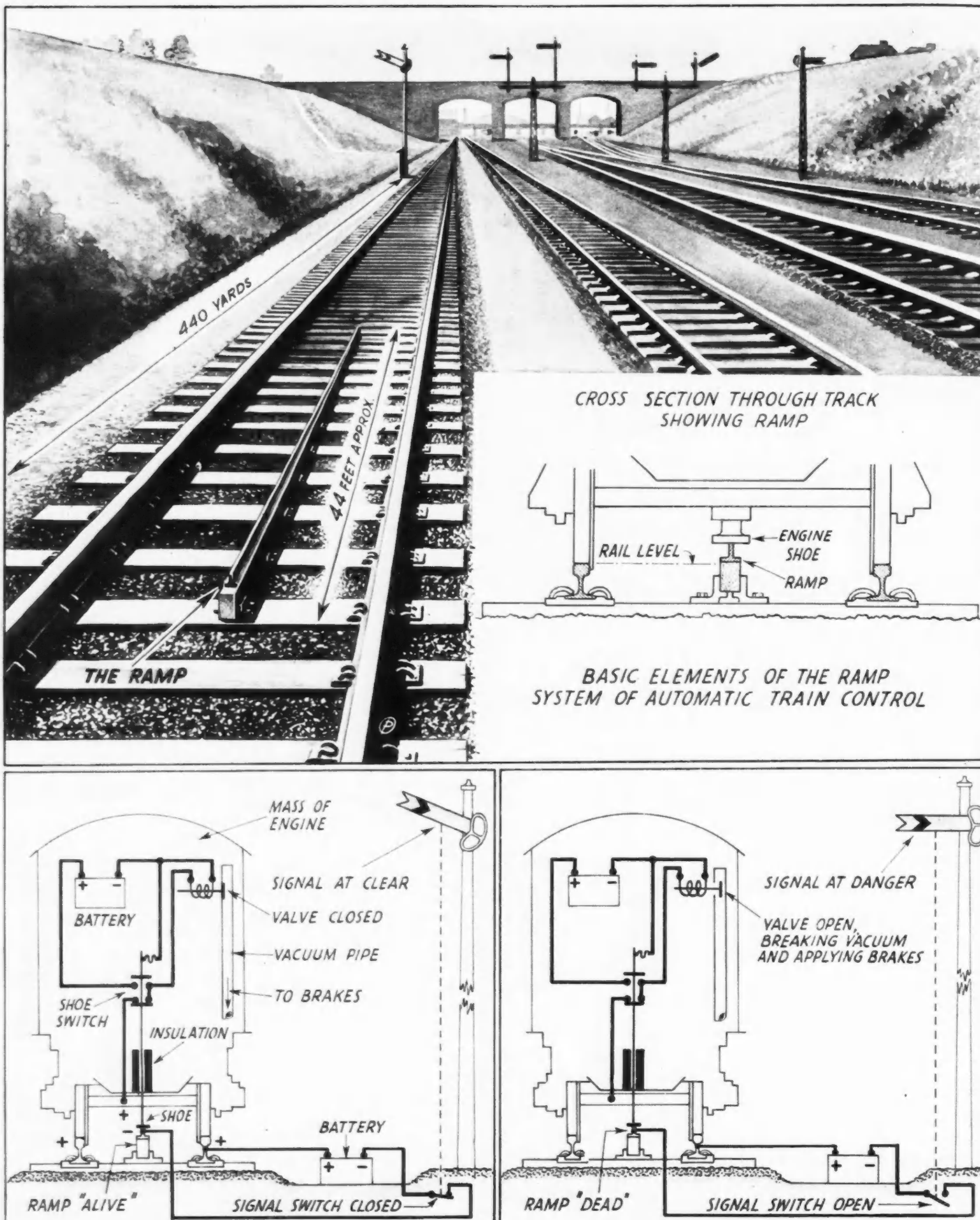

FIG. 1. These diagrams illustrate only the basic principle on which the ramp system of Automatic Train Control, as used on the Western Region of British Railways, is operated. In practice, there is a number of additions and modifications: for example, the brake valve solenoid has two windings, one supplied by the locomotive battery, the other by the ramp; there is a bell warning device; and a vacuum valve is provided, so that the battery is switched out when the locomotive is standing for lengthy periods.

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AUTOMATIC TRAIN CONTROL

J. H. M. SYKES

Assoc. I.E.E.

It is a paradoxical state of affairs that, after a hundred and fifty years of railway transport, while enormous attention has been devoted to the perfection of the block signalling method itself, the provision of colour light signalling, and track circuiting for giving every possible aid to the signalman and to the train dispatching operator, there still exists an almost complete lack of means of communication with the driver of the locomotive (other than reliance on his visual observation of line-side signals)—except on certain sections of the former Great Western Railway, on the former L.M.S. Shoeburyness line, and on the London Tube system.

Many hundreds of inventions have been patented or devised for the purpose of ensuring that at no time can a driver pass a signal at danger. The disastrous accident at Wealdstone in October 1952, in which 112 lives were lost is still the subject of official investigation, the results of which must not be anticipated. Nevertheless, the public inquiry held immediately after the accident resulted in a clear suggestion from the Ministry of Transport's Inspecting Officer that a likely cause of the accident may have been that the driver of an express train, proceeding at full speed, passed not one but a total of three signals, all set against him. In view of a statement made at that inquiry, British Railways appear to be committed to immediate investigation of automatic train control systems which would make a similar accident impossible in the future.

Any device which has the purpose of providing automatic train control must fulfil a number of extremely rigorous conditions. First, it must be absolutely reliable, and if it does fail it must 'fail to safety'. This means that any failure, whether electrical, mechanical, pneumatic or from any other cause, must result only in giving the 'Stop' indication and must never give an 'All Clear' indication. Secondly, it must be capable of universal application. This condition means that the use of snow ploughs, for example, must not interfere with its functioning; it also means that all types of railway stock, whether steam, electric or diesel electric, must be able to pass over the route to which it is fitted, and be able to do so at any speed, high or low. Third, it must not involve any delicate apparatus, either on the locomotive or on the track, needing careful adjustment at frequent intervals. The maintenance of steam locomotives is carried out by personnel whose whole training has been in the direction of heavy mechanical equipment rather than the care of precision instruments, and it would not be feasible to attempt to provide in a short time an adequate service of skilled technicians who would be required at the large number of locomotive maintenance depots up and down the country if a system depending on intricate apparatus were introduced. Finally, the device adopted must be reasonably economic in operation, and it must be capable, moreover, of withstanding extremes of temperature and humidity, even greater than those normally experienced in this country.

Three automatic train control systems have in fact been in practical use in Great Britain. Over forty years ago, the Great Western Railway management decided to equip a very large proportion of their main lines with a ramp-operated device which will now be described in some detail.

THE RAMP SYSTEM

About a quarter of a mile in advance of the distant signal associated with the track section the train is about to enter, an insulated ramp is fixed between the running lines. This is about 45 feet long and the top edge—which consists of a steel bar of T shape—is about 3½ inches above the rail level. The ramp is slightly staggered on straight track, the ends being each 2 inches away from the centre line, in opposite directions.

Attached to the locomotive is a shoe mounted in an insulated holder and projecting below the locomotive, so that it will touch the ramp and so be lifted. In the cab a valve is arranged, connected to the vacuum brake apparatus, so that if the valve is open, air is admitted to the vacuum pipe, and the train is braked. The valve is normally held closed by means of a solenoid, or electro-magnet, which is supplied by a small battery carried on the engine. The circuit from the battery to the solenoid is taken through a switch, which is actuated by the shoe in such a way that if the shoe is lifted by passing over the ramp, the circuit is broken. This would result in the solenoid dropping off, the valve opening, and the train being braked by the admission of air to the vacuum pipe.

However, as the switch on the shoe is opened, a further switch is closed. If the distant signal with which the ramp is associated is off (i.e. in the 'All Clear' position), the ramp is connected, through an auxiliary switch moved by the signal arm, to a separate battery on the track, and this arrangement provides an alternative source of supply for the solenoid controlling the vacuum brake, this time *via* the track battery, the ramp and the shoe, the return circuit being made through the running rails. Consequently, the valve remains closed, and the train is able to proceed.

If, however, the distant signal is in the 'On' (or 'Danger') position, the auxiliary switch on the signal arm is not closed, and consequently there is no supply to the ramp from the track battery; thus, when the shoe switch interrupts the internal battery circuit, the solenoid drops off, and the brake is applied. At the same time a vacuum-operated siren sounds, and a bell rings.

The apparatus used by the Western Region of British Railways includes a number of alterations and improvements in addition to the basic elements briefly outlined above. An indication can be given to the driver even if the signal is 'Off'. The system has proved extremely satisfactory in service, and the accident record on the routes which comprise the Western Region shows that its results have been well worth while. The limitations of the system are that the ramp projects above rail height, which precludes its application where snow ploughs have to be used, while the low clearance of the electric motors on certain

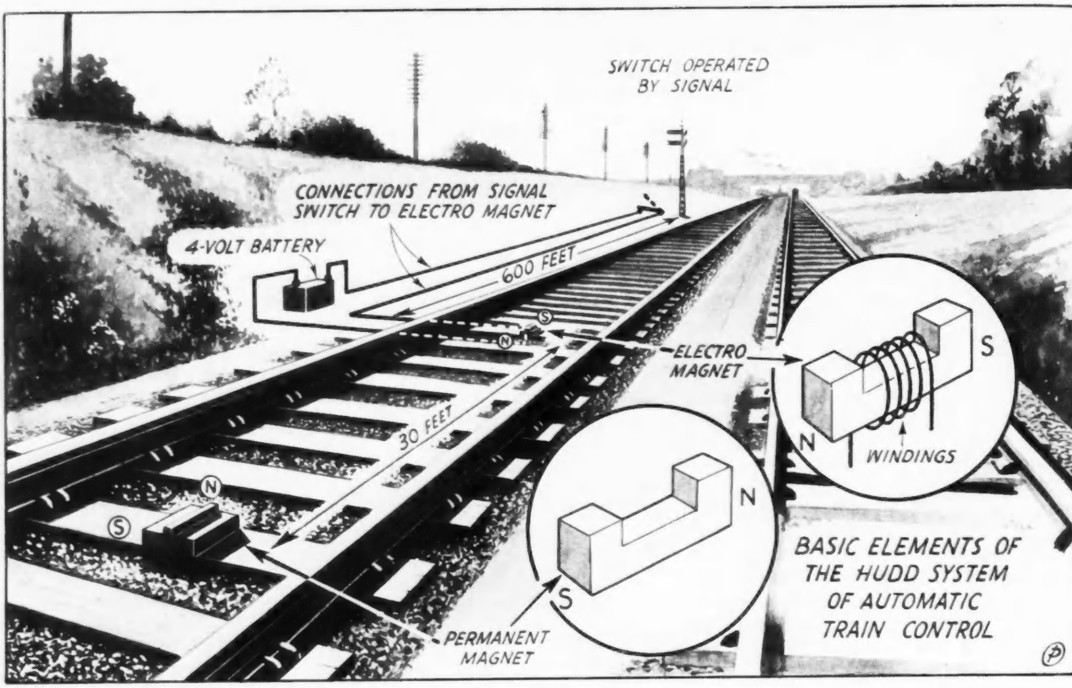


FIG. 2. The Hudd system of Automatic Train Control, installed on a small section of the London Midland Region of British Railways, employs two magnetic elements fitted between the track rails, as shown. These act on a magnetically operated brake valve on the locomotive, which projects downwards to within a few inches of these elements.

types of electric and diesel electric stock means that such vehicles cannot pass over lines equipped with the ramp.

THE HUDD SYSTEM

The second system to be considered is employed on the London Midland Region of British Railways on the Fenchurch Street–Shoeburyness line only, and is known as the Hudd system. It comprises two magnetic elements, mounted at the centre of the track, between the rails, about 600 feet before the distant signal to which the device applies. The first magnetic element encountered by the train is a simple permanent magnet, and 30 feet farther on a second element is installed. This comprises an electro-magnet supplied by a 4-volt battery whose circuit is interrupted by an auxiliary switch (as in the ramp system) actuated by the signal arm. If the signal is in the 'Danger' position, this circuit is broken and the electro-magnet is not energised.

On the locomotive, a pick-up device is fitted which involves no electrical equipment at all on the locomotive itself. In essence, it comprises a pipe connected to the vacuum braking system, which is normally closed by a magnet, and which projects to within about 5 inches of the permanent magnets on the track.

When the train approaches the distant signal, it first passes over the permanent magnet, and this has the effect of causing the magnetic element on the brake pipe to move, by ordinary magnetic induction, and so open the pipe to admit air. In a very brief interval of time, the locomotive has proceeded 30 feet and so passes over the second element. If its electro-magnet is energised (i.e. if the signal is 'All Clear'), the polarity is such that it reverses the action of the permanent magnet and closes the brake valve once more. Thus, the train can proceed. If the signal is in the 'Danger' position, the magnet is not energised, and so the work done by the permanent magnet in opening the brake valve is not cancelled, and the brake is consequently applied.

Both the ramp system and the Hudd system have a number of modifications which have the effect of enabling the driver—once the device has given the warning—to cancel it and retain control of the train. In each case it will be seen that a failure of the device cannot lead to a false 'All Clear' signal; with both devices, if any part of the electric circuits were to fail, the brake would always be applied; this would also happen with the ramp system if the shoe were defective and did not make contact with the ramp itself.

THE UNDERGROUND'S SYSTEM

The third system in use on the railways of Britain is that utilised by the London Transport Executive on the Tube

railways. This takes the form of a train-stop, which is almost a necessity because of the high traffic density carried on the Tube tracks and the automatic signalling systems employed on the underground system. Of some 3281 stop signals 2726 are fitted with train-stops. These take the form of electro-pneumatic devices, of a similar reliability and certainty in action to those used for the points themselves. The train-stop is installed alongside the track, and if the corresponding signal is at 'Danger', an arm is moved so as to project in such a way that it will strike a suitably projecting portion of the train, and in so doing will open a cock to release the compressed air braking system, immediately applying the brakes and stopping the train. The remarkable freedom from accidents on the Tube Railways is no doubt due, in some measure, to the provision of these devices.

The Tube railway train-stop cannot be of universal application to main-line railways, as the very high speeds, sometimes exceeding 100 miles an hour in pre-war days, which have to be catered for, would render it uncertain in operation and liable to damage.

The railway authorities, so far, have announced that experimental work is being carried out on a device which will combine the advantages of the ramp system with those of the magnets used in the Hudd scheme. The cab equipment of the locomotive is likely to follow that provided in the Western Region, with a siren and bell arranged to give warning of signals at 'Danger' and those in the 'All Clear' position, while the track equipment is stated to be of the Hudd type. Automatic brake application will, of course, be incorporated.

Some foreign railway systems have had means for communicating the signal position to the driver for many years, although most of them do not go as far as actually stopping the train. The American scheme usually provides for coded indications to be transmitted to the driver, to give continuous information of the state of the signals ahead. At the signal box a code generator, which takes the form of an alternator generating 100-cycle current, is connected to the running rails through a code interrupter. This consists of a motor-operated cam device, breaking the circuit a predetermined number of times per minute. As an example, an 'All Clear' indication may be 180 pulses per minute, 'Approach' (for a distant signal) may be 80 pulses per minute, and the 'Stop' code is zero impulses per minute. On the locomotive, two induction coils, one near each of the front wheels, pick up the 100-cycle current and transmit it to an amplifier and a decoding device, which may take the form of tuned reeds or may be composed of filter circuits. Miniature signals in the cab are then actuated in accordance with the code signals received. Again the device 'fails to safety', since the absence of any signal from the pick-up, due to failure either on the track circuits or on the electrical equipment installed on the locomotive, will always give a 'Danger' signal.

Other methods of communicating with the driver of a moving train have been tried out. In early days, contact wires along the track were used, but these were unreliable in bad weather conditions. Nowadays, particularly in America and also in a number of continental countries, radio equipment is being extensively tried out. The problem of providing satisfactory continuous communication with a train which may pass through tunnels, or may travel in mountainous country and in areas where radio reception is always difficult, have not been entirely solved, particularly where the vast distances of North American transcontinental journeys are concerned.

To revert to the opening paragraph of this article, it is still strange to think that only now is widespread attention being given to the one safety device which has always been an obvious need on any railway system; and which—if it had been in operation—would almost certainly have saved 112 lives at Wealdstone last October.

THE COMPOSITION OF THE EARTH'S CORE

New evidence which sheds light on the composition of the earth's inner core was given in a paper by Professor K. E. Bullen to the recent 29th meeting of the Australian and New Zealand Association for the Advancement of Science, held in Sydney.

Professor Bullen of Sydney University has been studying the rate of transmission of earthquake waves through the different regions of the earth's interior. These waves vary in speed according to the density and elastic properties of the material encountered. By studying the arrival times of these vibrations at seismological observatories through the world, various properties of the earth's interior can be estimated.

"For some years it has been known that the earth contains a central core with a radius of 2200 miles," Professor Bullen said. "This is physically distinct from the outer mantle, which extends up the further 1800 miles to the earth's surface. Several distinct lines of evidence have pointed to the bulk of this central core being in a fluid state. Over the years from 1935 to 1939, it was concluded that the central core contained an inner core with a radius of about 800 miles. I have adduced some evidence to the effect that while the outer part of the central core is fluid, the inner core is solid, with a density at the centre about eighteen times that of water.

"There is some division of opinion on the question of the composition of the outer part of the central core, but my work favours the view that it consists of a high-density liquid form of silicate rock with a density about eleven times that of water, and that the inner core is chemically distinct and consists of iron, nickel and probably some denser metals."

THE WIDENING ORBIT OF POWDER METALLURGY

H. W. GREENWOOD

Early progress in applied science is always largely empirical. That has certainly been true of powder metallurgy and the range of empiricism has covered several thousand years, for both iron and steel were known in the Mediterranean basin before 1200 B.C., and ancient Egypt knew and used gold, silver electrum, copper, bronze and other metals, most of which occurred in powder form and hence had to be sintered or brazed or welded to produce pieces of any size. That ancient peoples could produce large masses of metal by such means is proved by the famous Delhi iron pillar; produced by the reduction and forging of iron from native ore about A.D. 415, the pillar weighs more than six tons and is over 23 feet in height. During the first and second dynasties in Egypt (3400–2980) gold was worked and methods of soldering it used to produce jewellery and ornaments. In Ireland in the eleventh century gold was mined and worked by methods which involved the melting and soldering of the metal, the production of sheet and wire and the making of many ornaments which found their way over much of Western Europe.

The history of chemistry and metallurgy tells of the production of over twenty metals, almost without exception in powder form, between the middle of the eighteenth and the middle of the nineteenth centuries. The classical example of Wollaston's production of malleable platinum by a purely powder metallurgical process is generally accepted as heralding the dawn of modern powder metallurgy. W. H. Wollaston slowly decomposed finely divided ammonium platinum chloride by igniting at not too high a temperature so that a loose, spongy, metal powder was formed. This he ground in a wooden mortar to separate the particles without burnishing them. He then sieved the powder, washed it and pressed it to form a cylindrical slug. This was then dried and heated slowly to a red heat on a charcoal fire. Heating was continued until the mass was sintered so that a strong bonding of the individual particles produced a coherent metallic slug. This was hammered and forged while still hot. Not only did this produce compact ductile platinum, but it could also produce thinly rolled sheets. Wollaston's method, with slight modifications, is still in use for the platinum metals and for a number of the more refractory metals such as titanium and zirconium.

For nearly a hundred years powder metallurgy as such made little progress. The production of flake metal powders by Henry Bessemer, the story of which he tells in his autobiography published in 1905, was the first large-scale production of the flake powders which are well known as gold and silver powders but which are so named, not because of their composition, but because of their colours. These powders are composed of very small flakes produced mainly by a stamping process. They are used in printing inks and for paints, but they have never played an important part in powder metallurgy. Their interest for the metallurgist lies in the fact that it was the profits Bessemer made from his flake powders which financed his experiments in steelmaking, and the powders themselves had but little effect in stimulating any interest in powder metallurgy as we know it today.

SELF-LUBRICATING BEARINGS

A much more important item was the patenting of a process in the United States in 1870 covering the pressing of tin powder for the production of journal boxes and thus providing the prototype of the self-lubricating oil-impregnated bearing which for many years was the best known and most important product of powder metallurgy. Gwynn, the patentee, pressed tin turnings which were mixed with petroleum residues. From providing a journal box which would allow of high speeds and yet obviate the danger of seizing up as well as the necessity for frequent oiling or lubrication, it was but a short step to the production of self-lubricating bearings for all kinds of small machines, especially those such as typewriters, sewing and washing machines having a number of bearings not easily accessible which could not be oiled without difficulty; the same type of bearing was needed in machines, such as those used in the textile industry, where leaking oil would damage material passing through the machine. There is no doubt that the performance of the porous bearing and its increasing use in industry led to the study of problems involved in the sliding contact of metal upon metal and to the recognition of the part that soft metals could play.

From this has come the wider use of lead and of indium in bearings, also the evolution of the steel-backed bearing first with porous metal lining only, later of the oil reservoir type. While the advantages of porous metal produced by powder metallurgy were thus developed and applied, the disadvantages of porosity could not be overlooked, and so there began a progressive evolution in means of utilising the porosity of the powder metallurgically produced metal which in the beginning had been the source of the weakness and poor physical properties of almost all sintered compacts. Metallurgists had before them the example of infiltrating or impregnating the porous part with oil, and it was not a very different problem to infiltrate or impregnate the porous part with another alloy or metal having a melting point distinctly below that of the porous part.

From very simple conditions and combinations, one of the earliest being the infiltration of an iron porous part or skeleton with molten copper, there has arisen a technique whereby a remarkable series of combinations have been produced which have themselves solved many problems already, have removed the reproach of poor physical properties due to porosity, and have opened up avenues full of interesting possibilities. The process of actual infiltration can be carried out in several ways: one can place a piece of the lower melting point metal on top of the porous

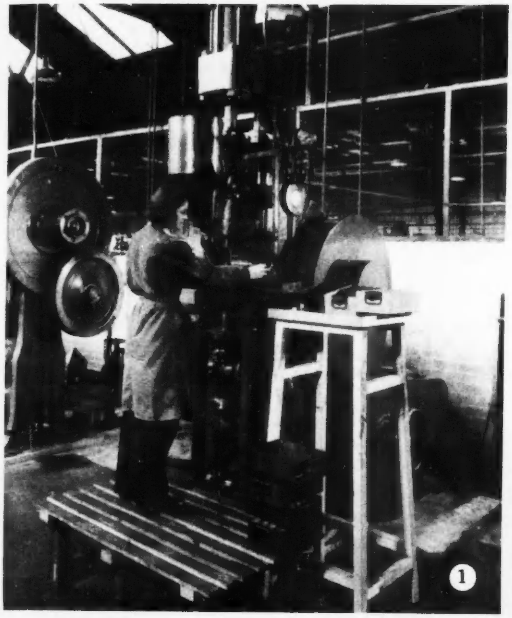
MAKING COMPONENTS BY POWDER METALLURGY

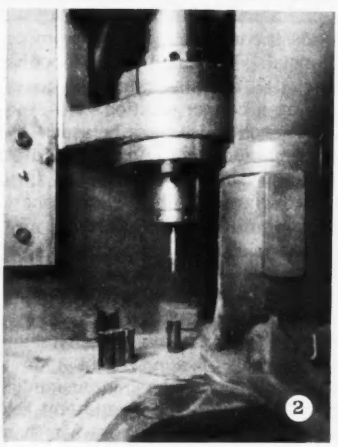
FIG. 1. The die set in a press is exactly filled with powdered metal. The press then compresses the powder to give a 'green pressing'.

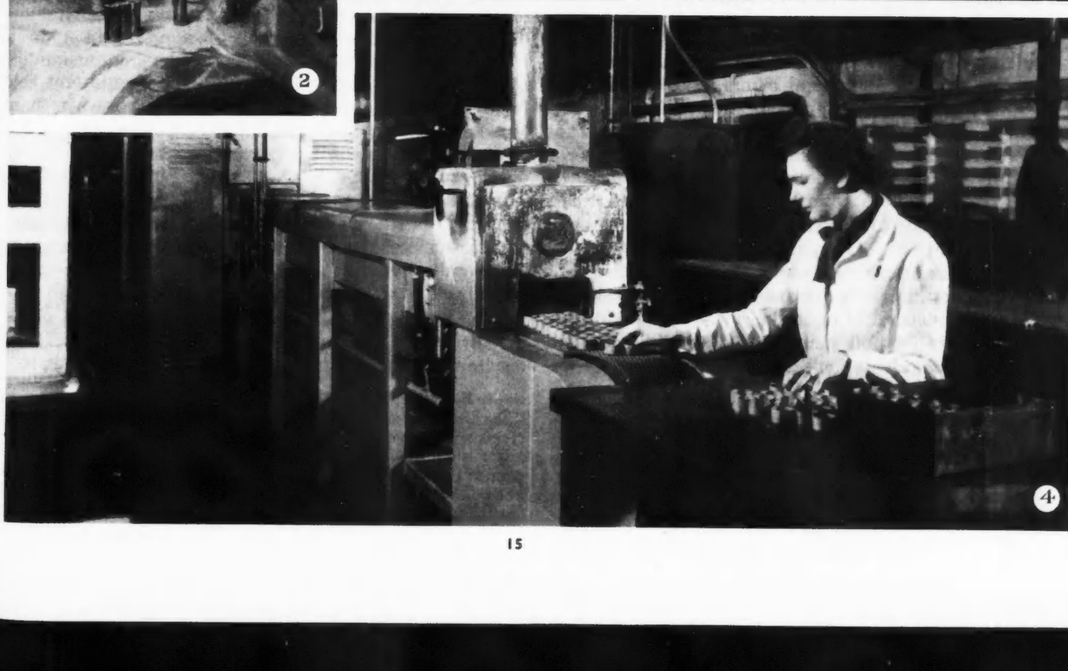
FIG. 2. A green pressing being ejected by the lower punch at the close of the pressing operation.

FIG. 3. The green pressings are then fed into the sintering furnace, the base of which is a travelling belt. The sintering process is carried out in an inert or a reducing atmosphere to prevent oxidation of the pressings. The bed of the furnace moves at such a speed that the pressings are completely sintered by the time they have passed through the hot zone of the furnace.

FIG. 4. From the hot zone the sintered pressings pass through a cool zone, and they are cool enough for comfortable handling by the time they reach the operator.







part, heat the two while in contact to a temperature just above the melting point of the infiltrating alloy or metal and allow capillarity to distribute the molten metal through the porous pressing, or the latter can be immersed in a bath of the molten metal; if necessary the process can be carried out in a vacuum when the procedure is called impregnating. Heating is by gas or electric muffle or vacuum furnace. A recent use of this infiltrating technique has been to use a modern plastic having a very low coefficient of friction such as tetrafluorethylene; when this has infiltrated into the porous metal the resultant material provides a bearing surface or film having most desirable properties.

The extent to which infiltration has been efficacious in overcoming the poor physical properties of pressings can be realised from a couple of examples. When a porous iron part was infiltrated with copper alone a tensile strength of 67,500 pounds per square inch was attained. Replacing copper by a copper-aluminium alloy capable of age-hardening* brought the tensile strength up to 81,900 pounds per square inch. (This method must include the treatment necessary to develop the age-hardening of the alloy.) Using a somewhat different infiltrant containing manganese as well as aluminium and copper, tensile strengths of 93,500 pounds per square inch were obtained.

So far one might well consider the progress outlined as being a step-by-step empirical development, but parallel with the progress made during and since the war there has been the development of a theoretical approach in which the metallurgist has called in the chemist, the crystallographer, the physicist, the physical chemist and even the atomic physicist, to give aid and to suggest new paths to be followed and new problems to be solved. Much attention has been given to examining minutely the factors that can influence properties, in particular the effect of small amounts of impurities. A field in which this particular subject is proving of great interest and value is the influence of specific impurities in the control of age- or precipitation-hardening. Already it has been shown that the addition of quite small quantities of particular elements can have an effect far beyond anything that might have been anticipated. This has happened in general metallurgical practice as well as in powder metallurgy. An outstanding example in general metallurgy has been the production of malleable cast iron by the addition of from one to two parts of magnesium or cerium per thousand parts of iron. Another example is the effect of a few hundredths of one per cent of sulphur added to nickel alloys of the permalloy type; this addition results in an even-sized grain structure when the alloy is hot-rolled, whereas at room temperature it is so brittle that it can be easily ground to powder. In connexion with the effects on ageing characteristics, it has been shown that the order of effect is largely dependent upon the small solubility of the added element in the bulk material, and it is now accepted that whether a hardening effect may be expected or not will largely depend upon the solubility of the element used. The degree of control that can be exercised will prove an economic factor of the first importance for it is being found possible by such additions to accelerate the onset of the reaction and also to shorten the time necessary for the full ageing to take place.

It is unnecessary in these days to stress the importance of the economic factor. It obtrudes and intrudes in every direction. One preoccupation of the powder metallurgist is the wear of die and punch in the press used for pressing powders. The two essential operations in powder metallurgy are pressing and sintering. Pressing consists in filling the powder into a die which shapes the powder by the pressure of two punches, one above, the other below. The press may be mechanical or hydraulic, depending on the size of the articles to be pressed and the pressure required. When the powder has been pressed in the die it is called a *green pressing*, and must pass on to the sintering operation in which the pressing is heated in a furnace at a temperature below the melting point of the metal comprising the pressing. Obviously if a powder is hard it will not only call for heavy pressures to mould it, but will also scratch and wear the die and the punch faces. Yet the cheapest iron powder is cast iron, but it is very hard and angular and therefore causes severe wear of the dies, for example. A most ingenious method of overcoming this difficulty has been found. It consists in giving the powder a thin coating of a soft metal. For this purpose copper has been found most efficacious. The powder can be coated electrolytically or by using a copper solution. If advantageous, other soft metals such as lead can be used. The effect of this coating is to give good green pressings at quite moderate pressures, and after sintering at from 980° C. to 1000° C. in a slightly reducing atmosphere components having good tensile strength and good machinability are obtained.

The infiltrated iron compacts in which age-hardening alloys are used as infiltrants have a parallel in the newly developed technique of infiltrating tungsten and tungsten-carbide compacts with cobalt-based alloys of the vitallium or hastelloy type thus opening up a new field in heat-resistant and extremely hard materials having outstanding resistance to corrosion and wear. A most important field in powder metallurgy is that of the carbides known as 'hard metals', which are usually carbides of titanium and tungsten cemented with cobalt or nickel. Hard carbides were first developed by Krupps during the First World War. Tungsten carbide was used first and was cast, but this proved so brittle that resort was had to fine-grained carbide powder cemented with cobalt or nickel. These pressings were sintered at such a temperature that the cobalt and nickel were melted during the sintering and so provided a liquid phase. It was found later that most of the carbides had a slight solubility in this liquid phase. The resultant products were a great improvement, but as they

* Age-hardening and precipitation-hardening are the result of one metal being a solvent for another, such solubility being dependent upon the temperature of the metal acting as solvent. If such a metal is heated and dissolves a given quantity of metal, and is then suddenly cooled or quenched, a portion of the dissolved metal separates out, usually as some particular alloy of the two metals, and so increases the mechanical properties of the alloy. The difference between age and precipitation hardening is that the former takes place somewhat slowly by the separation out of fine particles at room temperature. If the alloys be heated at moderate temperatures sometimes the process can be accelerated and is called artificial ageing. Using appropriate infiltrants and treatment, tensile strengths of over 100,000 pounds per square inch have been attained. The copper-infiltrated iron compacts have the additional advantage that they can be brazed together without fluxing, and thus the assembling and building up of complex parts from simpler units is facilitated.

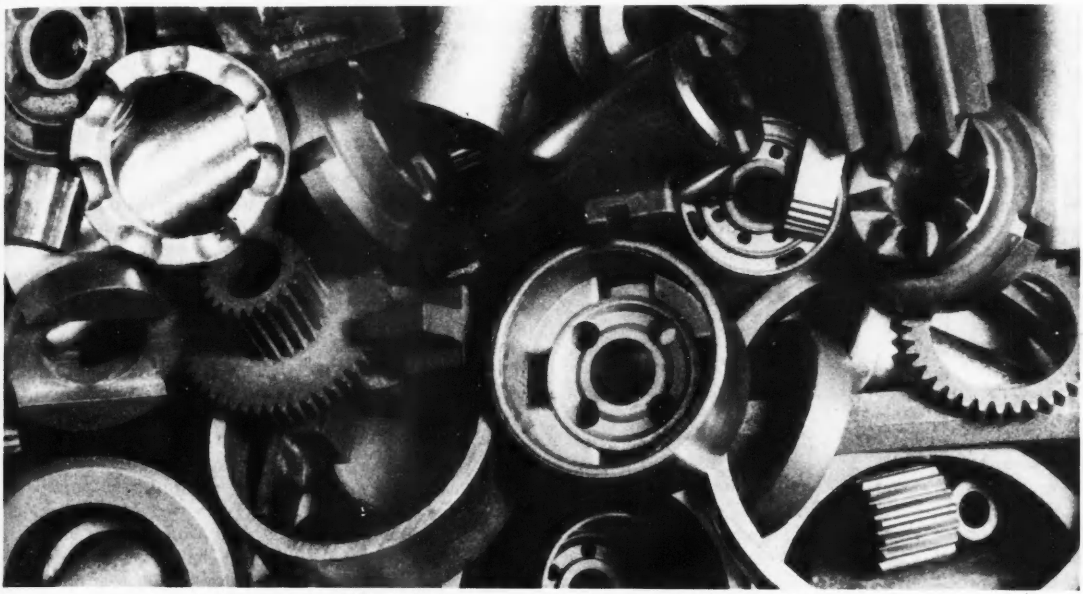


FIG. 5. The diversity of form exhibited by products of powder metallurgy: all these are iron parts.

came to be more widely used it was found that defects developed when they were used to cut certain materials. After considerable investigation a cure was discovered which consisted in using a certain percentage of titanium carbide mixed with the tungsten carbide. That initiated a close study of the effects of mixing various carbides, the effect of using different metals as cement and, in fact, every aspect of this particular branch of powder metallurgy. As a result not only has tremendous progress been made in the production with certainty of particular properties, but the inherent brittleness of tungsten carbide has largely been overcome so that it is now possible to use hard metal in the production of percussion drills as well as rotary drilling tools. Today the hard metals are rapidly replacing other more difficult and more expensive materials for dies of all kinds, from those used for drawing fine wire, to those used for the pressing of large parts by powder metallurgy. A field of big potential value is that in which hard metals provide the dies for hot pressing.

POWDER METALLURGY AND GAS-TURBINE DEVELOPMENT

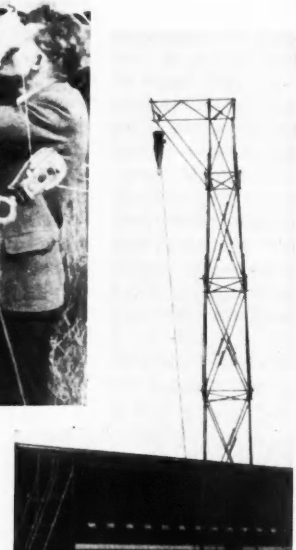
In no field has greater interest been aroused than in aeronautical engineering and especially in the production of metals and alloys capable of withstanding not only high temperatures, but stress at high temperatures. This is the realm of the gas turbine and recent developments have shown that this country is well in the foreground of progress. It has been clear for some time that there is no open road to further advancement; that in the case of the gas turbine there is no great amount of room for improvement in increasing the efficiency of compressor and turbines. Equally, higher temperatures, although not difficult to generate, are very difficult to employ for it is a fact that the metallic materials now in use are being run at temperatures very close to the limit of safe and useful employment. Little can be done in the reduction of stresses, and the metals that have higher melting point and which retain reasonable strength at higher temperatures suffer from serious practical defects. An example is molybdenum which readily oxidises in the atmosphere issuing from a gas-turbine combustion chamber where only about 20% of the oxygen is utilised and the remainder comes away at a very high temperature. Here it may be possible to use protective coatings of ceramics or possibly ceramic-metal mixtures, or in some cases pure ceramic parts. In all these possibilities a powder metallurgy technique is almost certain to be required.

By now the ever-widening orbit of powder metallurgy should be evident. It is, in fact, bewildering in its breadth and comprehensiveness. In the background remains the insistent call for more and more investigation and research. Moreover, much of that work must be fundamental in character. It is vastly more enlightenment and knowledge of the properties of materials that we want, and accurate information on how to control and apply those properties. (*Photographs by courtesy of Sintered Products Ltd.*)

BOOKS FOR FURTHER READING

There are no elementary books on powder metallurgy, the best general introduction to the subject is *Principles of Powder Metallurgy* by W. D. Jones, published by Edward Arnold (1937). There is the very complete and comprehensive *Treatise of Powder Metallurgy* by Claus G. Goetzel, in three volumes (Interscience Publishers, 1949–52).

Two important publications are *Symposium on Powder Metallurgy* (1947), published as Special Report No. 38 of The Iron & Steel Institute, and Volume 9, *Selected Government Research Reports, Powder Metallurgy* (1951).



FIGS. 1 and 2. A suction trap being hoisted on a tower. Below the fan unit is a gauze cone ending in a collecting tube. The disk-dropping apparatus is within the cone.

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THE AERIAL DISPERSAL OF APHIDS

C. G. JOHNSON

Ph.D, D.Sc.

For some years now we have been studying, at Rothamsted and at the barrage balloon station at Cardington in Bedfordshire, the aerial movements of insects, especially aphids. There are two reasons why we chose aphids. Firstly, some of them are serious pests. Secondly, from spring to autumn they make up, over Britain, a considerable proportion of those myriads of small insects which are blown about the sky by the wind; aphids thus form a very large and fairly homogeneous mixture from which to take samples, and the lessons we learn from them are very relevant to problems connected with the dispersal of many other insects. This article deals mainly with aphids, but the general significance of the approach should be kept in mind.

Now at certain times in their life histories, many insects become winged; they may then fly perhaps a few yards, or sometimes even hundreds of miles. We know something about the factors which regulate the comings and goings of many insects; how their movements are affected for instance by the weather, the locality or habits peculiar to a particular pest. But although a great many *facts* are known about all this, we are still far from being able, even for one single pest, to assemble them into a really satisfactory picture of the whole process of dispersal and crop infection; this is true even for aphids on which so much work has been done. It is very desirable that we should possess such a picture so that eventually more effective control and precautionary measures may be developed.

Let us consider these matters as exemplified by the aphids. These insects are sometimes so numerous that they can devastate a crop merely by feeding on it. This can happen quite commonly, for example with the familiar black aphid of beans, *Aphis fabae*, which largely makes this crop uneconomical in Britain. On the other hand, one can have a situation in which the aphids are too few in number to cause much direct harm to the plants they feed on but still do a great deal of damage by infecting the crop with a virus disease.

What, then, are the elements in the dispersal of aphids which lead to a wholesale invasion of a crop?

Flying aphids invading crops in the spring come from other plants which otherwise may be of no agricultural importance. The black bean aphid comes from spindle trees and guelder rose; the principal carrier of virus in potato and sugar beet, the aphid called *Myzus persicae*, winters on many different kinds of plants, including species of *Prunus*, e.g. the peach. There are, therefore, three parts to the invasion story. First there is the growth of the insect populations on their winter host plants, and the effects of weather and natural enemies on the number produced; then comes the second part, concerned with the movements and adventures of these insects once they are airborne; and finally there is their descent on to crops—that is the invasion proper.

Now the numbers of aphids (and other insects) in the air varies according to the season, and even from day to day and hour to hour (Fig. 3). On a heavily infested bean crop between 50 and 100 *million* aphids may leave each acre in a single day at the height of an infestation. During the daytime there is a continual liberation of huge numbers of aphids into the air as they fly from plants on which they have bred; conversely there is an equally impressive invasion of trees and plants, for these insects do not remain aloft for more than a few hours. And we usually do not know beforehand either when or on what scale this turnover between aerial and terrestrial populations will occur. How, then, can one anticipate these unpredictable events in a way which enables them to be studied thoroughly and in relation to the conditions which preceded and accompanied them?

One way is by a sampling apparatus or trap which will measure, continuously and automatically, the numbers in the air at different times of the day and night. Changes in the numbers may then be linked with possible causes, such as the weather conditions, which can be recorded simultaneously. Of the many kinds of insect traps which were available when we began these investigations, none was really suitable for our purpose. Some, like light traps, act only at night; others, like nets and sticky traps, function satisfactorily only when the wind blows, and therefore vary in efficiency. There were no traps which recorded the migration process as it changed hour by hour, or even within the hour; nor did any trap exist which registered the volume of air that had been sampled in obtaining a particular catch, and before we could begin to study the insect *density* and its changes we needed a trap capable of

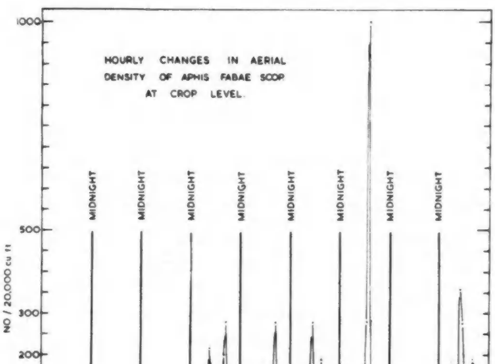


FIG. 3. The changing density of flying aphids over a bean crop. Each dot represents an hourly density. Flight is diurnal, each daily catch increasing as the population grows. (Density is measured by number of aphids per 20,000 cu. ft. of air.)

doing that. Our preliminary investigations showed, in fact, that although trapping had been practised by entomologists for many years, no one had troubled very much to standardise the instruments.

We therefore proceeded to design a trap which tells how many insects there are in a given volume of air, and how this number changes (Figs. 1–2, 4). Its action depends on an electric fan which sucks in air—and insects—and it works equally well in light or darkness, rain or fine, wind or calm. As some of the traps have to operate 2000 feet up in the sky suspended from a barrage balloon, we could not keep on emptying the traps by hand; so we arranged that metal disks should fall automatically into the collecting tube of the trap, so sealing off the catch obtained during one hour from that of the next hour; this arrangement enabled us to get samples of the insect content of the air at different times of the day and night.

All this work on trap design was only a preliminary to the real work of the investigation, the aims of which are to measure the effect of weather changes on the amount of migration from infested crops; to try and find laws which govern the way in which insects are dispersed by air currents once they are airborne; and the process by which crops and host plants become invaded at the end of the chain of events.

Take the first of these; the results are interesting, particularly because they illustrate that a *population* of animals does not necessarily follow the laws governing the behaviour of its individual members.

For example, although aphids are very weak insects they are not easily blown off a plant: indeed the stronger the breeze, the tighter they cling. For this reason it might be expected that fewer aphids fly on windy days, and that therefore most migration occurs in calm weather. But this neglects an important point. Aphids have fantastic powers of reproduction and can double their numbers in twenty-four hours. This can mask the opposite effect of the reluctance of individuals to fly when conditions are unfavourable. It has, of course, been fully recognised in the past that the prime factor making for a good or bad aphid *season* is the number of aphids produced. But the numbers flying from day to day or even during a day always seem to have been regarded as being due merely to the willingness or reluctance of individuals to fly on account of the weather conditions. What has not been appreciated until quite recently is that the actual changes in numbers in the air even during a single day are also largely due to changes in the numbers of winged aphids—a population effect rather than a behaviour effect, and one which takes place very rapidly. Aphids do not take flight at night, but the last stages before the winged form usually continue to moult during the night and early morning, changing into winged aphids. There is thus a regular tendency for winged aphids to accumulate between the time that flight stops in the evening and the time it starts next morning. Each day, therefore, sees the discharge of accumulated populations and the magnitude of this discharge depends only partly on the trigger action of weather-controlled flight behaviour; but it is considerably influenced by the numbers of aphids which have recently moulted, and also by the length of the maturation period separating the time the last moult is complete and the time the winged insect is ready to take the air.

VIRUS-FREE PLANTS IN APHID-FREE REGIONS

Remembering, too, that a breeze capable of moving smoke but not a weather vane is sufficient to blow an aphid off its course of flight, it is not surprising that we found that the numbers of aphids migrating are neither very strongly correlated with the weather conditions of the moment, nor are they by any means confined to calm air conditions. Both findings run contrary to accepted beliefs and aphid migration is, in fact, largely a wind-borne process. This does not mean, however, that calm weather is unimportant in the aphid story. For it is in calm weather that large crowds of these insects are able to fly about voluntarily among crops, visiting plants here and there without being dispersed by wind; it is these conditions which make for the spread of virus diseases within crops and also between neighbouring crops. It is obviously important to know when and why such special kinds of flight occur, and how the rises and falls of the population coincide with conditions favouring or preventing the local accumulation of crowds of flying aphids.

Take potatoes again as an example. Much virus is spread by winged aphids which come into the crop in spring and also by those which develop from populations bred on potatoes during the summer. It is important in farming practice that this spread should be limited and if

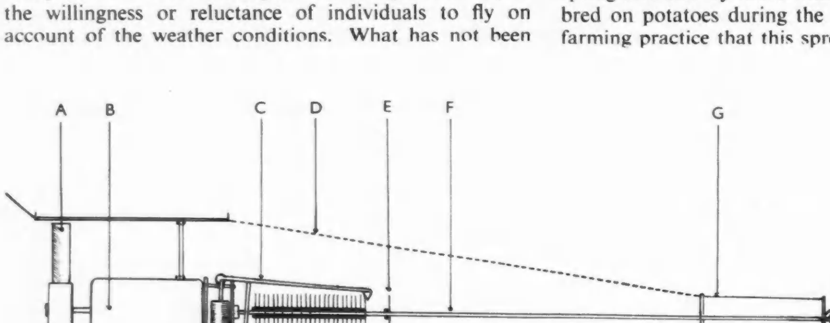


FIG. 4

MECHANISM OF THE SUCTION TRAP

- A Fan.
- B Electric motor.
- C Device for releasing disks.
- D Gauze cone.
- E Disk for segregating the hourly catch falling down the guide rod (F).
- G Collecting tube.

possible prevented, especially in seed potatoes, for unhealthy stock produces poor crops. In Britain it is possible to grow healthy seed in some parts of the north and west, where, because of the topography and because winds come mainly from the Atlantic, these areas are relatively free from invasions of virus-bearing aphids. In some other countries, such as Holland, this isolation is not possible and the seed potatoes must be lifted or the tops destroyed before the virus has spread seriously. It is necessary then to be able to time and, if possible, to predict the aphid migration.

Occasionally, however, even the isolated areas in Britain are invaded by enough virus-bearing aphids to introduce disease. This is due to the other kind of migration—long-distance, windborne journeyings. Fortunately many kinds of viruses do not last long enough in the insect to survive a few hours' journey, but there are some which do.

We have begun to study the mechanism of long-distance migration at Cardington, where we suspend traps from a barrage balloon cable and take samples at heights of 2000, 3000 and 4000 feet.

We may have as many as six traps flying at different heights at one time, so that we can follow the ebb and flow of aphids in the air from near the ground to high in the sky. The traps are emptied every day, the aphids sorted out by hand from all the other insects, put into tubes of alcohol, labelled and booked to await identification. Up to fifty labelled tubes accumulate each day, and we aim to trap on most fine days all through the summer and autumn. Later each aphid must be checked individually under the microscope to find its species. (There are about four hundred different kinds in Britain.) We may catch many thousands of aphids a year, so the reader will appreciate that the mechanical part of the work is apt to be considerable before even a start is made on the statistical treatment of our data, an analysis in which the numbers of the aphids and their fluctuations are correlated with temperature, wind-speed, humidity and other factors.

In Britain, aphids are to be found everywhere, and it is not easy to follow the flight of a particular group over a long distance, for its members would quickly become lost among all the other aphids. Nor can we mark and liberate enough specimens to ensure us recapturing some of them elsewhere.

Long journeys are, however, sometimes more easily studied in other countries where a desert, large lake or sea separates a well-defined breeding site from an area which will be invaded. Then, since the region in between may be devoid of aphids, the travellers can be kept under observation without becoming lost on the way among other aphid populations. We have, therefore, studied the vertical dispersal instead, for the higher they go the farther they may travel and much can be learned from this aspect.

Ascending air currents cause aphids to be wafted up to heights of several thousand feet—13,000 feet is the highest recorded. They are sometimes blown for hundreds of miles and are still able to feed and reproduce. The longest single hop ever recorded was 800 miles across sea. The greater the altitude, the more sparse becomes the aphid population; thus at 2000 feet two aphids in a space equal to that of a good-sized room would be a crowd! In general (and there are exceptions) the distribution of aphids is

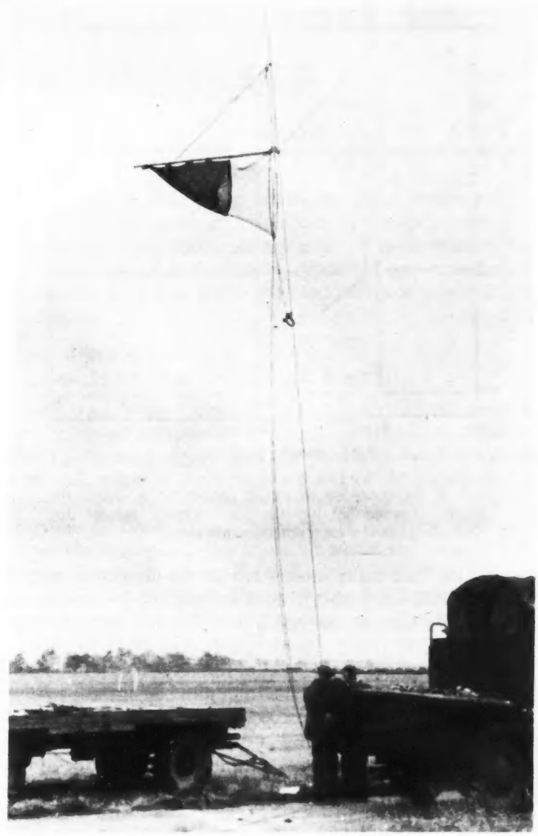


FIG. 5. Aerial tow-net opened and attached to balloon cable.

such as would be expected if they were wafted passively upwards and downwards against their will. It is encouraging to find, from a welter of data, that the proportions at different heights follow a law which can be expressed simply and mathematically (Fig. 6). As far as we have analysed figures for other insects, this appears to be true for most of those which are commonly found at high altitudes.

Now this relation of density with altitude is important, for not only do we have a good first approximation to a law for vertical dispersal, but its simple nature enables us easily to integrate the curve for the relationship of density to height. In other words, instead of having to work with figures of the density of the insect population *at* different heights, we can now estimate the total insect content of the air over a given area; or we can also estimate the total number of insects present in a zone between two heights, for example, in the 1000–2000-foot zone or the 0–1000-foot zone. So for the first time, changes in the whole aerial population, not just the changes in density at particular heights, can be considered. This gives a much more realistic view of the situation. For example, a table of densities at different heights shows high concentrations of aphids at low altitudes and vice versa. This gives an

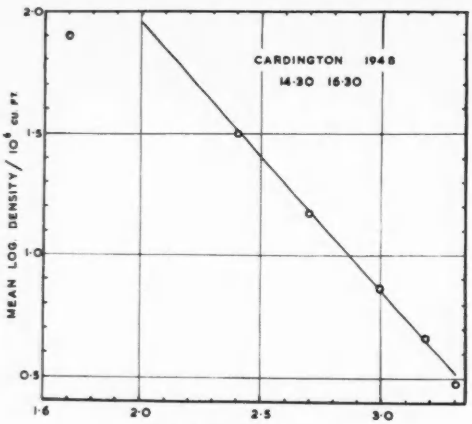


FIG. 6. Relationship of aphid density to altitude; the graph obtained by plotting log density against log altitude is linear over a considerable range.

impression that most insects are in the air nearer to the ground, which can lead to misconceptions; in the case of aphids, for example, one needs to realise that though these insects are very thinly distributed at high altitudes, nevertheless the high altitudes account for very large numbers of aphids, and about 70% of the total number of these insects in the air are found above 100 feet.

The use of an integrated curve therefore necessitates a different approach and a rather laborious technique in the analysis of the data, for we now must deal with the combined picture from all the traps rather than with each trap separately. On a fine day the air up to 2000 feet above a square mile of ground may hold two million aphids or more, apart from other insects. Most of these are above the tops of the tallest trees and if they stayed there no one would worry. But they descend more or less regularly every day. We do not understand fully how they do this. Some are brought down by descending air currents and choose to remain down, especially at night. But it is possible that some may cease to fly because of exhaustion or because of the cold. We would like to know how long aphids remain in flight under different weather conditions and different physiological states; we also want to know how long they may remain aloft when flight ceases, for on this ability will depend how far they will be blown. Our observations show that only a small proportion—under 30%—of the aphids in the air during the day, usually remain in the sky throughout the night. So, in spite of the difficulties of studying the long-distance spread across the countryside, there are many things still to be learned about the upward and downward movements of these insects.

And it would be wrong to imagine that just because aphids are weak fliers, wafted willy-nilly by the slightest breeze, that the whole process of dispersal is a mechanical one, depending only on meteorological forces. Both the start of flight and, what is perhaps more important, the events which lead up to alighting, if not always under the complete control of the aphid, are very much biological matters, depending on the behaviour of the insects as living creatures, not as inert particles. Their willingness to commence a migratory flight appears to depend on their acquiring a certain physiological condition, which involves a waiting period, and is not merely dependent on the suitability of the weather for flight. The character of their flight—whether it is a short, local flight of a few feet, or a prolonged period on the wing—is also a biological affair and may depend on the age of the insect. Certainly the character of flight at the beginning and end of migration is, as one might expect, different, and presents different problems to us. It is here that one must adopt a different approach and study the behaviour and even the aerodynamic aspects of flight of individuals rather than of populations. For example, we would like to know if calmness is necessary for aphids to alight successfully as it is for them to take to the air. From the economic viewpoint it would be desirable to know if different kinds of plants, the position of the crop in relation to shelter, or differences in the spacing of plants, give different degrees of protection from airborne aphids.

Thus millions of aphids (and other insects too) are scattered regularly over the countryside. Most of them may never find a crop, but at least a few have a good chance of doing so. Sometimes they remain together in high concentration, possibly after long journeys, and constitute a mass invasion. If we knew more about the mechanism of both small and large invasions we may be able to prepare more adequately against them.

Aphids are, however, but one kind of pest. All the hundreds of insect pests together are but a very small fraction of the world's insects. Many of these become windborne at some time and although most of them are winged forms, some are not. For example, very occasionally even insects such as wingless aphids get blown about; but they are not adapted to this kind of travel. Some wingless creatures are, however; there are the spiders which trail behind them a long silken thread which acts like a parachute, and then there are insects which have long hairs on their bodies—a mechanism making for great buoyancy when drifting in air. (An example is the Gipsy Moth caterpillar, a serious pest in the U.S.A., which is spread by wind.) Moreover, even with winged insects, windborne travel is not confined to the weak fliers; the general direction in which very strong fliers spread may be largely influenced by wind direction; locusts are an example. Nevertheless, all these insects whose spread is influenced by wind, behave as sentient creatures, and their reactions are of paramount importance not only at the start and end of a journey but also during the flight. It is not surprising, considering the enormous numbers of insects produced, that the various species sooner or later crop up in the right or in a suitable place, even if this is an extremely remote one such as an oceanic island. They thus may reach many places in the course of even a single season. How some survive and why others perish is very pertinent to zoologists, both pure and applied—but that is another story.

THE 17th-CENTURY REVOLUTION IN MATHEMATICAL PHYSICS

A. C. CROMBIF

B.Sc, Ph.D.

The dramatic event that made the 17th century one of the great turning-points in the history of science was the construction of the system of terrestrial and celestial dynamics due primarily to the genius of Galileo and Newton. This system was not only by far the most comprehensive ever put forward, embracing the whole universe and offering theoretical explanations applicable to all material bodies moving in space; it involved also the perfection of an entirely new mathematical method of explanation—*the method of explanation by means of functional relationships.* The fundamental rôle this method has come to play in the formulation and solution of problems both in mathematical physics and in nearly all other branches of modern science is the direct outcome of the revolution created by 17th-century dynamics.

This method of explanation by means of functional relationships came into use in the first place as the natural complement of systematic measurement, the purpose of which, in the experimental method, was to determine concomitant variations and define quantitatively the conditions necessary and sufficient to bring a phenomenon about. By expressing the factors to be explained (dependent variables) as functions of those conditions (independent variables), it could be shown precisely how changes in the former depended upon changes in the latter. To take an example from outside the field of dynamics, Kepler showed that the intensity of illumination (i) at any distance (d) from a source of light of luminous intensity (b) relative to a standard source, could be exactly expressed by the function $i = kb/d^2$, where k is a constant. Postulating b, d and k with given numerical values, a precise value of i must follow; any changes in b or d must lead to corresponding changes in i. The functional relationship explained observed differences of intensity by expressing its exact quantitative dependence upon two necessary and sufficient conditions.

The establishing of this method of explanation, normal and obvious as it now seems, was a revolution in scientific thought of the first magnitude. From the first controversies over Aristotle's and Ptolemy's physical and astronomical writings in the 13th century, down to the final triumph of the 'Newtonian' system, natural philosophers had been faced with the task not only of trying to find quantitative solutions of dynamical problems, but also of formulating the problems in such a way that they could be solved quantitatively at all.

The last-mentioned task was made possible only by a revolution in scientific thought that involved changes in both the philosophy and the techniques of science. The philosophical revolution had two main objectives: (a) to establish what may be called the 'descriptive', as against the 'essentialist' conception of scientific theories, which meant, broadly speaking, that a sufficient scientific explanation was given by a theory describing *how* changes in one quantity depended upon changes in others, without asking *why* this was so; and (b) to justify the use of unobservable theoretical entities, for example a body in inertial motion, to describe observable phenomena. The revolution in technique was the development of entirely new branches of mathematics for expressing the description as a functional relationship.

THE ESSENTIALIST CONCEPTION OF THEORIES

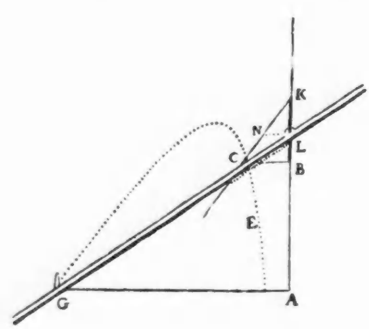
The distinction between 'descriptive' theories which merely 'saved the phenomena', and 'essentialist' theories which purported to give the real causes why the phenomena occurred, arose in the first place out of the fundamental Greek conception that observed changes in things were the outcome of underlying substances or essences with discoverable properties. For those who held this view, it was not sufficient for a scientific explanation simply to formulate a law describing an observed regularity; science must also discover and define the underlying substance which, so to speak, embodied the descriptive law and was the real cause of the regularity. Properties attributed to a given substance then determined the essential characteristics of an acceptable descriptive law.

One very good example illustrates the principles involved. A detailed set of properties was attributed by Aristotle to the whole gamut of terrestrial and celestial substances which he held to comprise the universe. He held that the material universe consisted of five basic elementary substances, among whose properties was the possession of what he called "natural places" in a series of concentric spheres. In the centre was the spherical earth, and round it came spherical envelopes of water, air and fire, respectively. These were the four 'terrestrial substances'. They were always being disturbed from their natural places, and, as a result, they united with each other to produce the various compound substances observed in man's habitation on the surface of the earth. Outside the envelope of fire came the fifth element, the 'celestial substance', of which the heavenly bodies and the transparent spheres bearing them were composed. This never combined with, or indeed ever met, any other substance, for the sphere of the moon (the innermost heavenly body) formed an absolute boundary between the terrestrial and the celestial regions. Outside the sphere of the moon were the concentric spheres bearing the other planets (including the sun) and the fixed stars.

The fundamental assumption underlying this Aristotelian system was that the premisses to be sought for scientific explanations of the physical world were definitions of substances, whose nature it was to act in a given manner. For example, the explanation of a falling stone was to be sought in the nature of the predominant elementary substance composing it, namely earth; and among the attributes defining earth was the possession of a natural place

at the centre of the universe. The 'natural motion' of a terrestrial element displaced from its natural place was to go in a straight line towards that place, where it came to rest. This explained why an observer on the surface of the earth saw stones fall and flames rise. A body could be moved in an 'unnatural' direction, Aristotle maintained, only by an external force. In the absence of any moving agent (which could be either an internal natural impulse or an external force), Aristotle held that a body would not move at all, a conclusion which he based upon the direct observation that in fact all bodies on the earth did eventually come to rest. The heavenly bodies moved as they did, he said, because the motion natural to the fifth element, of which they were composed, was uniform velocity in a circle. This motion was maintained by the action of the Prime Mover.

Already in Greek times difficulties began to arise from Aristotle's two basic dynamical principles: first, that every movement required a continuous efficient cause to maintain it; and secondly, that space had an organised qualitative structure with different natural directions for different substances. From the first principle was derived a 'law of motion', stating the *velocity* (v) was directly proportional to the *power* (p) or force of the moving agent, and inversely proportional to the *resistance* (r) of the medium: $v = kp/r$. An obvious defect of this 'law' was that a positive value of v should result from any finite positive values of p and r, yet a person pushing a heavy weight might fail to move it at all; also, where r was zero, as in a vacuum, v would be infinite. One consequence of the Aristotelian 'law' was especially important in forcing an eventual escape. In a given medium, where r was constant, v would be directly proportional to p, and there could be an increase in v only with an increase in p. Then what power maintained the velocity of a projectile after it had left the agent of projection, and what increase in power took place to make a heavy body accelerate as it fell?



Aprés cela prenant vn point a diſcretion dans la courbe, comme C, ſur lequel ie ſuppoſe que l'inſtrument qui ſert a la deſcrire eſt appliqué, ie tire de ce point C la ligne C B parallele a G A, & pourceque C B & B A ſont deux quantités indeterminées & inconnuës, ie les nomme l'vne y & l'autre x. mais affin de trouuer le rapport de l'vne à l'autre; ie conſidere auſſy les quantités connuës qui determinent la deſcription de cete ligne courbe, comme G A que ie nomme a, K L que ie nomme b, & N L parallele a G A que ie nomme c. puis ie dis, comme N L eſt à L K, ou c à b, ainſi C B, ou y, eſt à B K, qui eſt par conſequent $\frac{b}{c}y$: & B L eſt $\frac{b}{c}y - b$, & A L eſt $x + \frac{b}{c}y - b$. de plus comme C B eſt à L B, ou y à $\frac{b}{c}y - b$, ainſi a, ou G A, eſt à L A, ou $x + \frac{b}{c}y - b$. de façon que mul-

Sſ tipliant

FIG. 1. A page from Descartes' *Géométrie* (1637), in which he discusses the algebraic equation for a hyperbola.

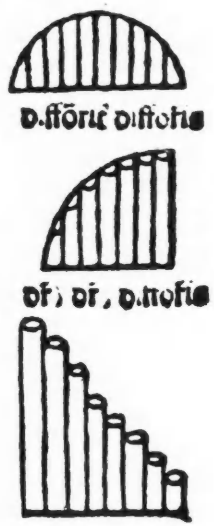
THE DESCRIPTIVE CONCEPTION OF THEORIES

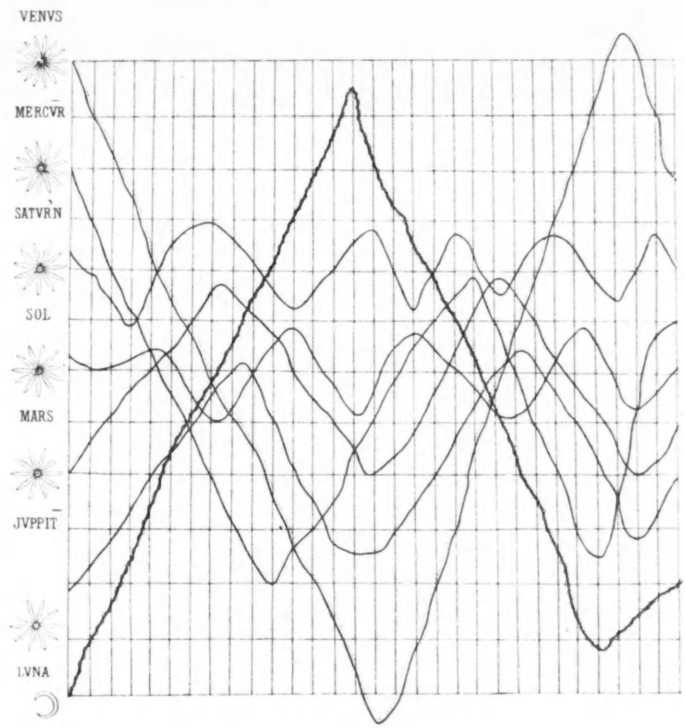
The possibility of purely descriptive explanations of the movements of bodies in space was first discussed by Greek astronomers, whose search for accuracy led them to put forward geometrical theories that could not be reconciled with these 'essentialist' explanations of Aristotle. In constructing his physical system, Aristotle had taken into consideration the concentric spheres used by Eudoxus and Callippus to describe the movements of the planets. The trouble began when these were replaced by other geometrical systems, and especially by the eccentrics and epicycles of Hipparchus and Ptolemy, which bore no relation at all to Aristotle's fundamental dynamical conception of natural motions. Out of the resulting controversy crystallised an explicit distinction between what were called, respectively, 'mathematical' and 'physical' theories, and two criteria, clearly stated by Ptolemy, for choosing between different mathematical, or descriptive, theories. These were that preference was to be given to the theory that 'saved the phenomena' most accurately, and with the smallest number of assumptions consistent with accuracy.

This distinction between 'mathematical' and 'physical' theories was kept up by Arab astronomers, and, with the revival of science in the West following the translation of Greek and Arabic writings into Latin in the 12th and 13th centuries, it became part of a general controversy over descriptive and essentialist theories in science as a whole. The background to the controversy was provided by the new experimental method being worked out by philosophers like Grosseteste and his successors in Oxford and Paris. A fundamental philosophical conclusion which followed from their analysis of scientific method was that, whereas a theory could be proved false by showing that it did not fit the observed facts, it could not be proved to be necessarily and finally true. It could be shown to hold over the range of observations made, but this could not prove either that future observations incompatible with it would not eventually be made, or that some other, perhaps very different theory, could not be constructed to fit the facts equally well. Of these characteristics of theories the history of astronomy provided many examples. So these medieval philosophers of science concluded that the confirmation of a theory by experiment or observation could not prove that the theory was a necessarily true statement of how Nature was actually composed and constructed. In other words, a scientific theory could not give an account of the substances underlying observed events; it could give only a

FIG. 2 (*right*). The earliest known graph. It shows the changes in latitude (vertical divisions) of the planets relative to longitude (horizontal divisions). From a diagram in the 11th-century manuscript, Munich 14436.

FIG. 3 (*below*). Diagrams in Nicole Oresme's *Tractatus de latitudinibus formarum* (Padua, 1486) representing different accelerated motions.





description of those events. The most complete account of this descriptive conception of theories was given by William of Ockham. Generalising Ptolemy's two criteria, he said in effect that 'essentialist' theories could not be considered at all in natural science, and that the only purpose of a scientific theory was to describe the facts of observation as accurately and economically as possible.

In the light of this conclusion Ockham was able to make an entirely new approach to the problem of motion, by simply ignoring the difficulties raised by Aristotle's dynamical assumptions. When we said "A body moves", he said, we simply stated that from instant to instant the body was observed to change its spatial relations with other bodies. It was irrelevant to discuss the efficient causes maintaining the motion, for example, of a projectile. The simplest assumption was that a body in motion would continue indefinitely to move of itself, unless opposed by a resistance. The only requirement for a scientific explanation of the movement was to give an accurate mathematical description of how the body changed its spatial relations with neighbouring bodies.

14th-CENTURY CONTRIBUTIONS

Had the mathematics available in the 14th century been equal to the task, the descriptive programme advocated by Ockham would no doubt have been carried through far more quickly than in fact proved possible. In the event, the dramatic changes that only centuries after Ockham's day created 'Newtonian' dynamics, and established the general conception and technique of functional explanations in physics, were preceded by a slow process of piecemeal criticism, reformulation, and rejection of the current physics derived from Aristotle.

The immediate problems leading to the revolution in dynamics came from the attempt to deal quantitatively with both persisting and accelerated movements. The first problem arose in connexion with the two phenomena, projectiles and falling bodies, discussed by Aristotle himself. Some later Greek and Arab physicists had pointed out that the efficient cause maintaining the velocity, for example of a stone after it left the hand throwing it, must be an internal tendency given to the stone itself by the thrower. In the first half of the 14th century a French physicist, Jean Buridan, took the crucial step of asserting that this internal tendency, for which he used the Latin word *impetus*, would maintain a uniform velocity *indefinitely* so long as the stone was not acted upon by opposing forces. Contradicting Aristotle's doctrine that a continuous external force was required to *maintain* velocity, Buridan said that the application of force would produce *acceleration*. *Impetus* itself as a cause of motion was the force or power possessed by a body, by reason of being in motion, of *altering* the state of rest or motion of other bodies in its path. Falling bodies accelerated because increments of *impetus*, added in each instant by gravity, produced increments of velocity. The measure of the *impetus* of a body was the quantity of matter in it (determined by relative density) multiplied by its velocity. This corresponded to Newton's definition of

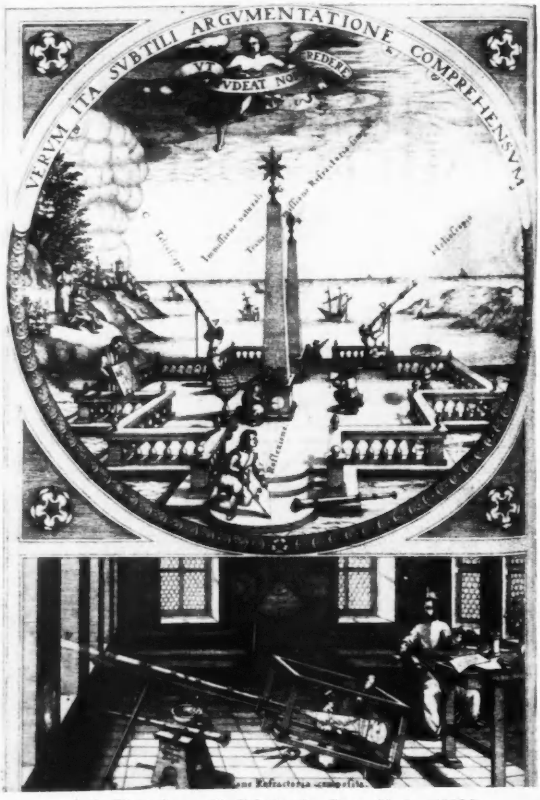


FIG. 4. Plate from C. Scheiner's *Rosa Ursine* (1630), showing observations on sunspots with the telescope and other instruments of the period.

momentum, and in fact the two terms were connected through Galileo's use of the Italian words *impeto* and *momento* as synonyms. An important difference was that both Buridan and Galileo held that the *impetus* of the heavenly bodies would maintain motion in a circle, whereas Newton's inertial motion persisted only in a straight line.

An especially important problem, made acute by Buridan's dynamics, was to find mathematical techniques for describing rates of change. The Greeks had disqualified themselves from this by maintaining a rigid distinction between continuous quantities like length, to be dealt with by geometry, and discontinuous quantities like number, to be dealt with by arithmetic and algebra. Motion they held to be a continuous quantity. Some contemporaries of Buridan, working at Oxford, first devised a method of dealing with rates of change, by treating motion as a discontinuous quantity which increased and decreased by amounts expressible in numbers. The method, known as 'latitude of forms', was soon given graphical representation and applied to changes of all kinds, for example of intensity of illumination and of heat. A 'form' was any variable quantity in nature, for example motion, light or heat; its 'latitude' was the numerical value of this quantity corresponding to any given 'longitude', which was an independent variable, usually space or time. Plotting longitudes along a horizontal line, latitudes were represented by vertical lines of specified lengths (Fig. 2). The line connecting the latitudes could then assume different shapes. With uniform velocity it was a horizontal straight line; with uniform acceleration (defined as the velocity of a velocity) it was a straight line making an angle with the horizontal; with uniformly accelerating acceleration it was a curve. By this method three Oxford men, John of Dumbleton, Richard Swineshead and William of Heytesbury, proved arithmetically, and a Frenchman, Nicole Oresme, proved geometrically, that in a given time a body moving with uniform acceleration covered a distance equal to that covered by a body moving uniformly with the velocity reached at the mid-point of time. Oresme's geometrical proof implied that the area under the curve represented the distance covered (Fig. 3).

These promising beginnings in the use of functions were stultified in the 14th century not only by the limited algebra and geometry available, but also by an incomplete escape on the part of most physicists from Aristotle's essentialist principles. A good example of this is the trajectory of a projectile deduced from Jean Buridan's theory of *impetus* by one of his followers; this trajectory, it was concluded, would be for a certain time a straight line in the direction of the projection, followed suddenly by a vertical line as the projectile fell to earth. This was easily shown completely wrong by artillerymen in the 15th and 16th centuries.

GALILEO'S CONTRIBUTION

Galileo's solutions of the problems of projectiles and of falling bodies illustrate the radical changes of technique and of philosophical approach that finally carried the day for the mathematical revolution in physics. Since the 14th century, a renewed interest in Archimedes and Apollonius, and the development of much of the basic notation and operational symbolism of modern algebra, had made Ockham's descriptive programme something more than a distant hope. Galileo reiterated this programme in his *Two New Sciences* (1638) when discussing falling bodies. He declared that he did not intend "to investigate the *cause* of the acceleration of natural motion, concerning which various opinions have been expressed by various philosophers . . . it is not really worth while"; he intended only "to investigate and demonstrate some of the properties of accelerated motion, whatever the cause of this acceleration may be". Using the same proof as Oresme, he showed that the velocity (v) of a falling body was a function of time (t) such that $v = \frac{1}{2}gt^2$, g being a constant determined by gravity. This function gave a *sufficient scientific explanation* of the dependence of v on t.

Galileo's trajectory for a projectile was something more than a technical achievement; he reached it by extending the descriptive conception of theories to include, in a radically new form, the explanation of the observable by the unobservable. Writing in his *Two Principal Systems* (1632) in support of the Copernican system, which appeared to contradict daily observation by asserting that the earth went round the sun, Galileo commended those who "with the sprightliness of their judgments offered such violence to their own senses, as that they have been able to prefer that which their reason dictated to them, to that which sensible experience represented most manifestly to

the contrary". His trajectory for a projectile depended upon ignoring not only Aristotle's qualitative theoretical distinction between natural and unnatural motions, but also all but a selected few of the factors affecting the observed motion of bodies. He transformed Buridan's *impetus* by deliberately abstracting from direct observation, imagining an ideal world in which there was no friction or air resistance, and pendulums swung on weightless strings. In such a world a perfectly spherical ball on a perfectly frictionless inclined plane would run up another plane in its path to exactly the height at which it was released on the first plane. If the second plane was lowered, the ball would have to travel a greater horizontal distance to reach the same height; if it was made horizontal, the ball would never cease travelling.

Applying the results of this beautiful 'thought experiment' to the problem of projectiles, Galileo assumed that, in the absence of opposing forces, the *impeto* of a projectile would maintain uniform velocity in a straight line. Ignoring air resistance, he said that the only factor disturbing this motion was gravity, which produced a constantly accelerated downward component of velocity, beginning as soon as the projectile was launched. The composition of these two motions, he showed, would give a trajectory that could be accurately described by a parabola.

The great advantage of this method of explaining the observable by means of the unobservable, not only for dynamics but for experimental science as a whole, was that it made it possible to find mathematical solutions of very complicated problems involving many variables. The problem was first simplified by leaving out all but selected factors which could be related by a manageable mathematical theory; this having been confirmed by controlled experiments, the complicating factors (for example, the effect of air resistance on a projectile's trajectory) could be reintroduced and incorporated into the theory, one by one.

NEWTON AND THE 17th CENTURY

Newton made far-reaching use of this simplifying method to complete the 17th-century system of dynamics. Abstracting even farther than Galileo from the observed world, he imagined a single body in empty, undifferentiated, infinite space. Such a body, he maintained, would remain either at rest or in a state of uniform velocity in a straight line. Reintroducing other bodies into this ideal world, he defined and measured 'force' as that which altered either this state of rest or the velocity or direction of the inertial motion. Applying to the heavens the dynamics worked out for terrestrial bodies, he then deduced Kepler's laws describing planetary motion, by assuming that each planet was attracted to the sun by a universal force of

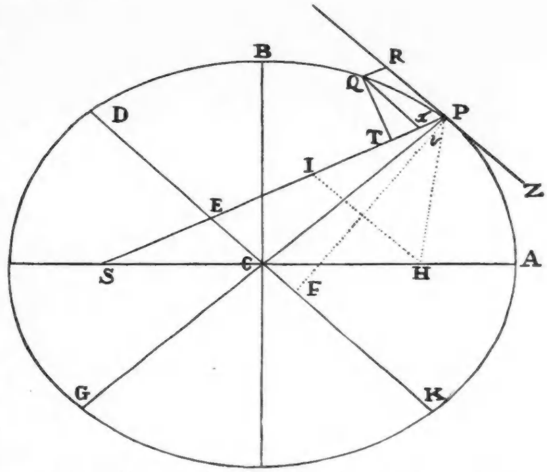


FIG. 5. Diagram from Newton's *Principia Mathematica* (1686), Book I, Proposition xi, Problem 6, in which he shows that the centripetal force, acting on a body P (a planet) moving in an ellipse round a fixed focus S (the sun), is inversely proportional to SP^2.

gravitation whose strength was inversely proportional to distance (Fig. 5). All this was done "*in a mathematical way*, to avoid all questions about the nature or quality of this force, which we would not be understood to determine by any hypothesis", he said in a famous passage in his *System of the World* (1686). *Hypotheses non fingo.*

The method of description, abstraction and functional expression, crowned with its first dramatic achievement in the Newtonian system, was soon applied over the whole range of physical science and eventually to physiology. Two new branches of mathematics, invented in the 17th century, were greatly to increase its power. Analytical geometry , which we owe in the first place mainly to three Frenchmen, Viète, Fermat and Descartes (Fig. 1), showed that to any geometrical shape there corresponded an algebraic equation, so that it was possible to solve geometrical problems by algebra. From this derives the universal modern use of graphs in combination with algebraic functions. A second new branch of mathematics comprised the differential and integral calculus of Leibniz and Newton, techniques which introduced an entirely new range of possibilities into the description of rates of change. With these new techniques the Greek scientific ideal of reducing the physical world to geometry opened out into the vastly greater modern programme for reducing it, without restriction, to what Descartes called a system of Universal Mathematics.

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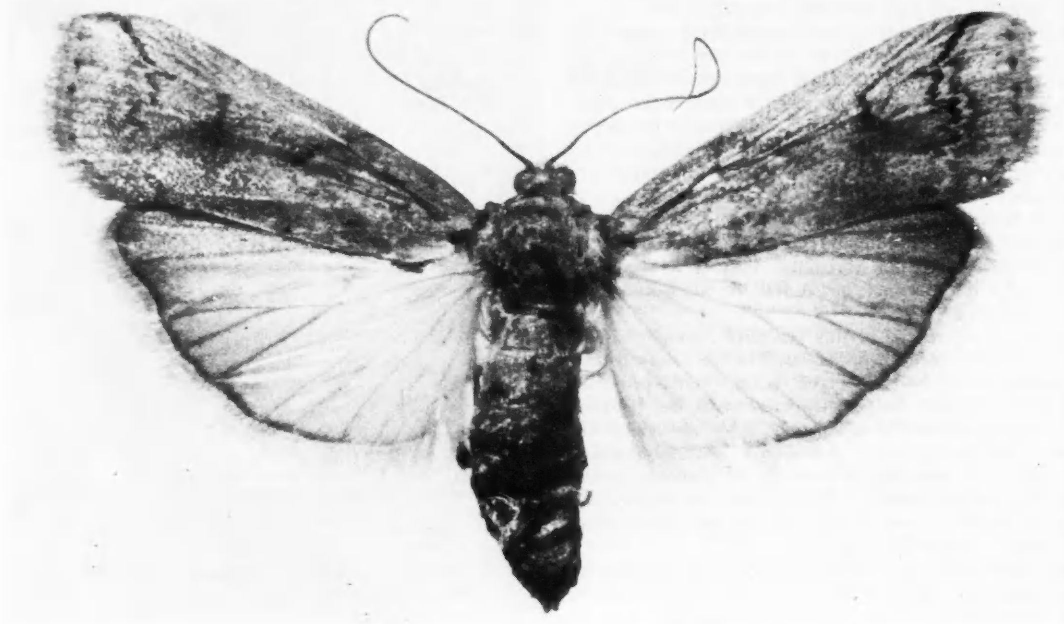


British Museum (Natural History) Photo, Crown Copyright

THIS MOTH SAVED AUSTRALIA'S WOOL GROWERS

The finest example yet recorded of the biological control of a pest comes from Australia. It is not long since the pest in question was threatening to ruin the sheep-farmers in many parts of Australia; the credit for its defeat must go to the caterpillar of a moth, and the scientists who chose that creature as the most effective agent for a continent-wide experiment in biological control. Today at Boonarga—a small railway siding on the western fringe of Queensland's Darling Downs—stands a building in dedication to this victory. Known as the Cactoblastis Memorial Hall, it was erected by settlers in appreciation of the *Cactoblastis cactorum* moth whose caterpillars dramatically conquered Australia's worst plant pest, the prickly pear.

Before the insect was introduced from South America, the cactus had become such a scourge that the settlers took to calling it the Green Octopus. An appropriate name in view of the fact that it had already smothered 60 million acres of fertile land. Much of this was valuable wool-growing country. It had devastated vast areas of 20- to 30-inch rainfall territory in Queensland and New South Wales. So rapidly had it spread that within two decades Australia faced a calamity in the increasing loss of productive lands. Nowadays the scene has changed miraculously. Land that was rendered virtually worthless by the cactus today has a value exceeding £100 million.

The records show that the prickly pear, *Opuntia inermis*, arrived in Australia more than a century ago. At first, landowners were impressed by the potential usefulness of the plant, and considered it would provide excellent hedges around their homesteads. The plant was in fact so highly regarded that one finds an instance, from Chinchilla—a few miles from Boonarga—of a workman being dismissed for failing to water a cactus hedge. Shepherds, too, welcomed the fruit of the prickly pear as a dish. Birds distributed the cactus seed far and wide, while the nomadic aboriginal tribes, carrying the fruit on their hunts, also aided its spread.

During the 'seventies the cactus gained a serious hold on a huge area of country. In 1883 the authorities decided that it must be eradicated. But it was then too late; the plant defied all attempts to check its spread. The once favoured cactus was now a national disaster.

By the beginning of this century ten million acres were affected, and the plant was still beyond control. The most rapid rate of spread seems to have occurred when stock were freely fed on prickly pear during the 1902 drought. The next twenty years witnessed the extension of the invasion until no less than sixty million acres were covered with the cactus. Holding after holding was deserted, and what had been good sheep land became a wilderness.

Left in undisturbed possession of the land it had won, the

cactus continued to flourish till eventually it formed a jungle impenetrable to man and beast. Cactus thickets were to be found stretching 900 miles down Australia's east coast, from Mackay in North Queensland to Newcastle close to Sydney in New South Wales. In places, the cactus belt extended 200 to 400 miles inland. Desperate efforts were made to check its spread; the cactus was dug up and burned, crushed and dragged out by the roots with rollers hauled by teams of horses or bullocks; costly poisonous measures were also essayed. But these measures did not succeed in halting the advance of the pest.

In 1923 a Royal Commission estimated that landholders had expended nearly a million pounds in trying to destroy the plant.

The Queensland Government had offered a large reward for a satisfactory means of destroying the cactus—originally, in 1901, a reward of £5000 was offered: this was increased to £10,000 six years later. Over 600 schemes of destruction—many from different parts of the world—were submitted to the Lands Department alone. But in 1924 one finds the Queensland Prickly Pear Land Commission reporting as follows: "To clear Queensland of prickly pear is at present quite impossible. The cost of the first clearing alone, even if practicable, would probably exceed £100 million."

The scientific members of another commission—the Queensland Prickly Pear Travelling Commission—were already scouring foreign countries for a remedy. A report from Argentina had raised high hopes, for a record of 1914 had been found which described how prickly pear growing in the Botanic Gardens at La Plata had been severely attacked by the caterpillar of *Cactoblastis cactorum*.

A small collection of caterpillars of this species of moth were sent to Australia, but fate again seemed allied with the plant scourge; the larvae died. So did enthusiasm for the insect as a potential weapon; at least for a whole decade. Meanwhile, cochineal insects were brought in from Ceylon, but the cactus casualties which resulted from the release of this species were negligible compared with the continuous spread of the plant.

From 1920 until 1927 the search for insect foes of the prickly pear continued. In all it was found that some 150 different species of insect breed and feed on the prickly pear and other cacti.

Selecting about fifty of these species, the Commonwealth Prickly Pear Board founded an insectiary in a Brisbane suburb. Here the insects were acclimatised and multiplied to form the nuclei of insect-breeding stations dotting the depths of pear-ridden Queensland and New South Wales. Scientists embarked on the project with some trepidation. For the imported insects might also ravage the land, attacking plants of economic value. Fears, however, were soon allayed by starvation tests; housed in cages, the insects —denied a diet of prickly pear—were confined to vegetables, fruit and commercial crops, as well as shade and timber trees, but there were no signs, however, that the insects did any serious harm to these plants.

The caterpillar of *Cactoblastis cactorum* emerged from these trials as the most effective killer of the prickly pear. Eventually, in May 1925, a collection of *Cactoblastis* eggs totalling 2750 was brought back to Queensland by a scientific mission which had been working in Uruguay and Argentina. The moths born a few months later produced 100,605 sticks of eggs. For eighteen months entomologists bred a vast insect army under cage conditions before releasing contingents near field stations.

Egg sticks—each averaging between 70 and 100 eggs—raised from the first Australian generation totalled 2,439,506. Distributing the egg sticks in such a way that the insects that hatched out would do the maximum damage to the cactus was perhaps the most tedious task of all. To guarantee that the larvae penetrated the pear segments, each egg stick had to be lightly gummed to a tiny square of paper which was attached to the plant with a pin or cactus spine.

For about three months each year gangs of men were employed in gathering the cocoons and eggs from the breeding cages; members of State authorities and landholders arranged to distribute them. Between 1925 and 1931 the number of egg sticks released totalled 2750 million. This vast operation was fulfilled at the moderate cost of £25,000.

The same piece of ground before and after *Cactoblastis* attack on the Prickly Pear.

Within the first four months of the campaign the results were phenomenal. The larvae bored relentlessly into the pest's pulpy segments, and even down to the bole and roots of the plant, and under its onslaught acres upon acres of prickly pear collapsed in dying masses. The end of the prickly pear's tyrannical reign was within sight.

From the time the first cactus plant was destroyed by *Cactoblastis* at Chinchilla the insect quickly extended its trail of devastation—even along the notorious 900-mile coastal belt. The year ended June 1930 witnessed the first major collapse of the plant pest; the area cleared by the insect in that year was at least 500,000 acres as against the previous highest yearly total of 30,000 acres. It was during that year, too, that the first reclamation of former prickly pear country began. Again, this was in the Chinchilla area.

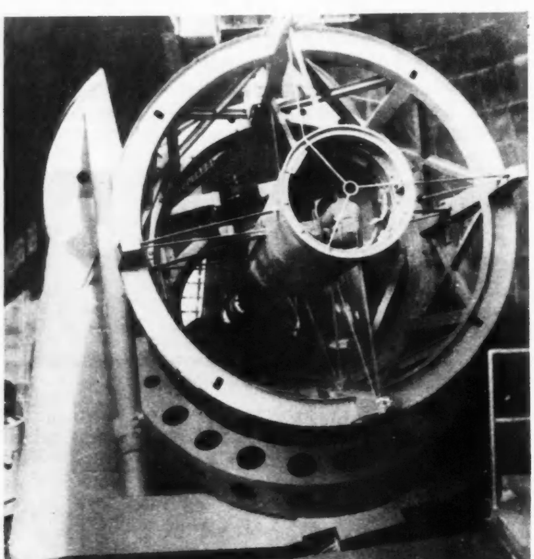
The insect's victory over the cactus was sensational. For instance, in 1930 many miles of land alongside the Moonie River still lay in the grip of the prickly pear. In the main, pastoral properties were derelict and deserted. Former big holdings were mere names on a map. The Dalby-St. George stock route was a narrow track, almost smothered by barrier walls of prickly pear. Here was the heart of Queensland's cactus-infected region. Yet two years later the cactus had been destroyed over 90% of this area. For the first time in two decades soil was again exposed, opening the way for hundreds of sheep-farmers to produce wool. By 1936 rehabilitation was in full swing; new pastures were being sown; homesteads were rising all over the country; dams were being excavated in greater numbers. By 1938 more than 500,000 sheep were grazing on reclaimed land along the Moonie River. There were minor resurgences of the cactus in the years that followed the successful clearing of such areas, and scattered plants of prickly pear are still to be found here and there, but it is never likely to assume pest proportions again.

DOUGLAS LIVERSIDGE

PALOMAR'S SKY SURVEY: A 4-YEAR PROJECT

A new picture of the universe, revealing details never known before, is taking shape as a result of the comprehensive sky survey now being made at the Palomar Observatory.

The survey, which is taking four years to complete and is now about half finished, will record on 1870 photographic plates more than three-quarters of the entire sky—all that is visible from Palomar—with a clarity and detail much greater than has ever before been possible. Outer space to a distance of 350 million light years from the earth is being photographed.



Looking down the tube of the 200-inch Palomar Telescope.

Palomar's Schmidt telescope-camera can photograph a sector of the sky as large as the bowl of the Great Dipper in one picture. This telescope is used in conjunction with Palomar's 200-inch reflecting telescope. The latter can penetrate into space three times as far as the Schmidt. Because the 200-inch telescope can photograph at one time an area of the sky only a quarter the size of the full moon, it is not suited for mapping the entire sky. Instead, it is used to photograph objects of special interest found in pictures taken by the Schmidt. Its pictures show many more details of far-distant stars.

The new photographs are revealing millions of new stars in the Milky Way, and it is now known that the Milky Way contains some 200,000,000,000 stars. Still farther out in space, the photographs are revealing many new nebulae which contain millions of stars, and are huge flat disks like the Milky Way. Thousands of these newly discovered nebulae appear on many single photographs, and it is now known that hundreds of millions of such nebulae exist.

These distant nebulae tend to form in huge clusters. Already the sky survey has revealed nearly one thousand such clusters, fairly evenly distributed throughout all parts of the sky, each containing many thousands of millions of stars. Before the sky survey was begun at Palomar, astronomers knew of less than 50 such clusters of nebulae.

These discoveries are adding a great deal of information to the astronomers' knowledge of the size and structure of the universe. Scientists at the Palomar Observatory hope to find the answers to many questions that hitherto have been unsolvable. One is the exact shape and size of the Milky Way galaxy.

When the sky survey is completed, the National Geographic Society plans to publish the photographs in a Sky Atlas, which will be available to observatories, schools and astronomers throughout the world.

Scientists estimate that the results of the survey will keep astronomers in the United States and other countries busy for half a century or more studying and analysing the new information it is revealing about the universe.

Far and Near

The 1952 Nobel Prize for Physics

Two American scientists, Prof. Felix Bloch of Stanford University and Prof. Edward Mills Purcell of Harvard University, shared the 1952 Nobel Prize for Physics.

Working independently of each other, Dr. Bloch and Dr. Purcell developed a method of measuring magnetic fields in atomic nuclei. Known as the Nuclear Induction Method, the technique is so far unrivalled for precision.

Dr. Bloch was a lecturer in theoretical physics at Leipzig, but left Germany after Hitler came to power. He moved to the United States, where he became Associate Professor of Physics at Stanford University. During the war he did research at Stanford and Harvard, and was also connected with the atomic bomb laboratory at Los Alamos. Before going to America in 1934 he had done research under both Prof. Heisenberg and Prof. Niels Bohr.

Dr. Purcell participated in the first physical measurements indicating that hydrogen is present in the 'voids' between the stars and our galaxy. He and his associates established with certainty that nascent hydrogen fills the cold silent reaches between the planets, the sun and the stars of the Milky Way. In 1949 he was appointed Professor of Physics at Harvard. From 1941–5 Dr. Purcell was leader of the Fundamental Development Group concerned with microwave work at the Massachusetts Institute of Technology.

Relaying Underwater Television Pictures from Ship to Shore

Scientists of the Royal Naval Scientific Service have carried their underwater television work (as described in DISCOVERY, Sept. 1952, pp. 293–6) a stage further, and have succeeded in relaying satisfactory pictures from ship to shore. This experiment was carried out off Portsmouth. A television camera from H.M.S. *Reclaim* scanned the sea-bed 16 miles away from Portsmouth, and good pictures were obtained on a television screen on land. The Admiralty states that 16 miles by no means represents the full range of the ship-to-shore link.

£100 Prize for Scientific Essay

The monthly magazine *Research* is offering two prizes (of £100 and £50 respectively) for 3000-word essays "discussing the possible industrial applications of some recent scientific investigation". The closing date for this competition is April 30, and readers are invited to write without delay for further details to: *Research*, 4 Bell Yard, London W.C.2.

Experts Meet to Fight Kwashiorkor

Nutrition experts of several nations held a conference in November, at Fajara in British West Africa, to examine problems of malnutrition in African mothers, infants and young children. Its main concern was Kwashiorkor, a deficiency disease due to lack of protein in the diet. It is most serious among infants when they are weaned on to almost completely starchy diets; its symptoms include the change of hair colour, which sometimes turns reddish. Experiments have shown that this protein deficiency can be corrected by feeding skimmed cow's milk.

Delegates from the Governments of Belgium, France, Portugal, Southern Rhodesia, the Union of South Africa, Britain and African territories attended the conference. The British delegation included Professors B. S. Platt and A. A. Moncrieff.

Fish Farming and Artificial Manures

Fish farming has a great future in the Colonies where there is an urgent need to increase supplies of first-class protein. Fish-ponds have a high yield; thus in Central Africa some fish-ponds produce more than a thousand pounds of fish a year, where the land previously produced, by grazing, only a hundredth of that weight of beef.

These points were made by Dr. C. F. Hickling, the scientist who is Fisheries Adviser to the Colonial Office, in his recent lecture to the Royal Society of Arts on the expansion of Colonial fisheries.

The importance of scientifically developing fish farming was emphasised in the following passage from his lecture: "Fish can be grown in rice-fields, rice can be grown in fish-ponds. Fish-ponds can be in brackish water, fed by the estuarine tides, and reclaimed from salt swamp or mangrove swamp, or they can be wholly in fresh water. In either case, fish can be raised either extensively, using only the natural fertility of the soil and water, or intensively, using fertilisers to increase the natural food of the fish, and food for the fish themselves. In the latter case, the waste products of the fish so fed add to the fertility of the pond. Fish-ponds are run in conjunction with pig and duck industries; in the case of piggeries, the food supplied to the pigs serves a double function. It fattens the pigs for market, and the excrements of the pigs passes on into the fish-ponds to nourish the food on which the fish feed. It is very economical. I myself feel that the future lies more in the study of and the application of inorganic fertilisers to fish-ponds. This is because waste foodstuffs, generally surplus to human requirements, are likely to grow scarcer as population pressure increases. So a fish farmer cannot count indefinitely on getting food for his fish. As to organic fertiliser, such as manure, this also is likely to become scarcer as more intensive cultivation of the land develops. But German research has shown that very great increases in the yield of fish can be secured by the treatment of the water in the fish-ponds with lime and superphosphate only, and we should apply this finding, and elaborate it, in tropical fish-ponds."

A Rare New Zealand Lizard

The London Zoo has been presented with a tuatara (*Sphenodon*) by the New Zealand Department of Internal Affairs. This lizard used to be common on the New Zealand mainland before the arrival of Europeans, but is now extinct there. Today it occurs only on a few small islands in Cook Strait, where it is strictly protected. It is the sole living representative of a reptilian order (the Rhynchocephalia) which flourished mainly in the Triassic and Jurassic periods. Anatomically it is interesting as it possesses a 'third eye'—the pineal 'eye'. Readers are referred to the DISCOVERY article about the tuatara entitled "Last of an Ancient Race" and published in our June 1951 issue.

Tracking Whales by Ultrasonic Echoes

Eleven of the whale catchers now at sea for the whaling season opening on January 1 are fitted with ultrasonic-echo 'whale-finders', which work on the same principle as the echo sounders used for tracking fish shoals. The new instrument is able to pick up a whale up to 2000 yards away, and the ultrasonic 'searchlight beam' involved can be kept trained on the animal all the time the whale catcher is getting within harpoon range (about 20 yards).

Britain Makes Cortisone

Cortisone acetate is now being made commercially for the first time in Britain. Between 1949, when cortisone was first used in medicine, and the present time all supplies have been imported from the U.S.A.

The drug is being produced in the West Molesey factory of Bayer Products Ltd. The starting material is a steroid substance derived from ox bile. A very great amount of research has been undertaken by drug houses throughout the world to find an alternative starting material for the synthesis and manufacture of cortisone acetate, but, so far, no more commercially satisfactory starting material has been discovered, although cortisone acetate is now being made elsewhere from a few other sources.

Canada and Britain Discuss Atomic Power Programmes

A conference between representatives of Canada and Britain, held at Harwell in November, discussed the immediate and long-term objective of the Canadian and United Kingdom programmes on the industrial application of atomic energy, the economics of nuclear power production and the production of special materials required for these programmes.

Australia's Atomic Energy Commission

The Australian Minister for Supply has announced the appointment of an Atomic Energy Commission to "control all Australian activities in uranium and atomic

Dr. Jaime Torres Bodet, who resigned his post as director-general of Unesco in November after a reduction in the Unesco budget had been passed at the annual conference by 29 votes to 21. He had been director-general since 1948, succeeding Dr. Julian Huxley, the first holder of the office.

energy". Its activities will include the mining and refining of uranium, the surveying and prospecting for uranium ore and scientific research and development of atomic energy for defence and industrial purposes.

A Gas Turbine Burns Peat

An open-cycle internal combustion gas turbine to burn peat has successfully completed its initial test runs at the works of Ruston & Hornsby Ltd. of Lincoln. The turbine, of 750-kW capacity, has been built under contract to the Ministry of Fuel and Power as part of the research programme into the utilisation of peat resources.

During the tests, powdered peat was used. A system of feeding the peat and controlling its flow into the combustion chamber has been developed which enables the plant to be run as steadily with this fuel as with oil. In this machine the hot exhaust gases can be used to dry the peat; the quantity of heat thus available is insufficient to dry raw peat (which contains about 90% of water), but the plan is to run the turbine in association with a special press designed to remove about two-thirds of the water from the raw peat.

It is intended that these trials should culminate in transferring the turbine to a Scottish peat bog where it can be tested in combination with a press and a dryer.

Research in Universities

THE Stationery Office has just published a book entitled *Scientific Research in British Universities 1951–2* which gives details of research work being carried out in universities and colleges in the United Kingdom. This volume, which was prepared by the D.S.I.R. and covers all fields of science and technology including agriculture and medicine, is unique and the information it contains has previously been confidential. The price is 8*s*., post free 8*s*. 6*d*.

Neptunium occurs in Nature

THE first trace of natural neptunium 237 has been discovered in ore from the Belgian Congo, it was reported to the American Chemical Society's national meeting held recently. This discovery fulfils the prediction made by Dr. Glenn T. Seaborg about five years ago that this isotope—first synthesised in 1942—and the atomic fuel plutonium would be found in minute quantities in nature.

Only a minute quantity of neptunium 237 has been isolated from the African pitchblende ore, and scientists will probably have to rely for any usable quantities on the synthetic material obtained from the cyclotron bombardment of uranium or from the operation of uranium piles.

Tea-tree Oil: A Correction

Mr. A. R. Penfold, Director of the Museums of Applied Arts and Sciences, Sydney, asks us to point out that in the article "Germs Defeated" by R. W. Richards (September 1952), the statement that "terpineol is the active principle of the oil of the Australian ti-tree" is incorrect. Although its odour is largely due to this substance it is only a minor constituent. Mr. Penfold also mentions the fact that the spelling "ti" is prevalent in commerce and technical circles but is, in point of fact, not correct, as the common name for *Melaleuca alternifolia* is "tea-tree". This is frequently confused with the ti-tree, an entirely different New Zealand shrub.

Night Sky in January

The Moon.—Full moon occurs on Jan. 0d 05h 05m, U.T., and also on Jan. 29d 23h 44m, and new moon on Jan. 15d 14h 08m.

The Planets.—Mercury is a morning star during most of the month, rising at 6h 50m on Jan. 1, but later on it draws too close to the sun for favourable observation. Venus is an evening star, setting at 19h 50m, 20h 30m and 21h 10m on Jan. 1, 15 and 31, respectively. The stellar magnitude of the star averages −3·9 during the month and the visible portion of the illuminated disk varies between 0·65 and 0·52. Mars is an evening star and sets about 20h 35m during Jan. Its stellar magnitude varies from 1·2 to 1·3 and at the beginning of the month it is a little south of θ Aquarii. Jupiter is visible until the morning hours, setting at 3h 10m, 2h 10m and 1h 15m on Jan. 1, 15 and 22, respectively. Its stellar magnitude averages −2·1 and it moves slowly eastward by about a degree in the constellation of Aries during the month. Saturn is a morning star, rising at 1h 40m, 0h 45m and 23h 45m at the beginning, middle and end of the month, respectively. Its stellar magnitude is about 0·9 and it can be recognised a little north-east of α Virginis (Spica). The earth is at perihelion, that is, it makes its closest approach to the sun—91,446,000 miles—on Jan. 2.

A total eclipse of the moon takes place on Jan. 29–30 and is visible in the British Isles. The circumstances of the eclipse are as follows:

Moon enters penumbra	Jan. 29d	20h 40·1m
" " umbra		21h 54·1m
Total eclipse begins		23h 04·6m
Middle of eclipse		23h 47·3m
Total eclipse ends	Jan. 30d	00h 29·9m
Moon leaves umbra		01h 40·4m
Moon leaves penumbra		02h 54·5m

The Bookshelf

Modern Radiochemical Practice by G. B. Cook and J. F. Duncan (*Oxford University Press, London, 1952, 407 pp., 42s.*)

The importance of radiochemistry as a research tool and in the development and applications of nuclear fission to the national problems of industry and defence has grown steadily since the first nuclear reactor was started in Chicago in 1942. It is then not surprising that the branch of chemistry devoted to the preparation, properties and manipulation of radioactive materials can already be considered an essential subject, at least in outline, in the education of serious students of chemistry today. There has, consequently, grown a need for guidance, in text-book form, in the general techniques of radiochemistry.

Drs. Cook and Duncan have written a book "to give detailed guidance in the practical aspects of the subject". The first half of the book is a readable discussion of such topics as radiochemical separations, the nature and laws of radioactive decay and the assay of radioactive isotopes. There are also sections dealing with the statistical aspects of random particle counting, the principles and design of electroscopes, ionisation chambers, counting tubes and the associated electronic circuits. The second half of the book deals with such topics as radiation hazards and laboratory design. There is also a unique collection of practical experiments suitable for the advanced student of chemistry (pp. 284 *et seq.*).

It will be seen that, besides dealing with the practical aspects of the subject, the authors have tried not to neglect the theoretical basis. This appears to be a weakness of the book. In attempting so much, both theoretical and practical subjects have suffered. For example, the section on statistical errors (pp. 58 and 284) is unbalanced and likely to be confusing to the student knowing nothing of statistics.

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Less attention might have been paid to auxiliary electronic circuits and tabulated fault finding. Greater attention to activation analysis, isotope effects on reaction rates, radiation decomposition and the use of additives such as aniline in improving the yield of certain Szilard-Chalmers reactions would have been more appropriate. There are some minor mistakes or misprints, but none so serious as to preclude easy elimination in future editions. For example, the half-life of bromine-82 is given as 34 hr. on p. 260 and 36 hr. on p. 361.

The format is attractive and the printing of the high standard usually expected of the Oxford University Press. The book will certainly be invaluable to the student of chemistry with ambitions in the Didcot direction or with an interest in radiochemistry for its own sake. It would not, however, be recommended to the biochemist or biologist requiring an introduction to the isotope tracer technique; for this purpose there are more suitable books such as Kamen's *Radioactive Tracers in Biology* (latest edition, 1951), and Siri's *Isotopic Tracers and Nuclear Radiations*. F.P.W.W.

The Atom Story by J. G. Feinberg, with a foreword by Prof. F. Soddy, F.R.S. (*London, Allan Wingate, 1952, 243 pp., 15s.*)

The months after Hiroshima brought a host of so-called popular books about nuclear physics, but few of them filled the bill so far as the lay reader was concerned, apart from a few notable exceptions, such as the revised edition of A. K. Solomon's *Why Smash Atoms?* and Chapman Pincher's *Into the Atomic Age*. Many of the books were semi-technical rather than popular, and they did not enjoy sales comparable with those of the official Smyth Report, which covered the wartime atomic project effectively but which assumed a fair knowledge of the basic principles of nuclear physics established prior to 1939. Another outstanding book, written at about the same technical level as the Smyth Report, was *Atomic Energy*, the Pelican book edited by J. L. Crammer and Prof. R. E. Peierls; the 1950 edition of this is still well worth recommending.

In 1950 there was still room for a new popular work on nuclear physics, but most publishers had by then reached the conclusion that the subject was exhausted for the time being. The time was not propitious for starting to write another book, but Dr. Feinberg happily disregarded the omens and went ahead with this work. It is a comprehensive account which begins with the atomic ideas of the Greeks and ends with the hydrogen bomb. About half of the book is devoted to pre-fission discoveries and ideas, the rest to the discovery of nuclear fission and subsequent developments—a reasonable apportionment of space, which enables the author to give up-to-date facts and still have room to make the basic principles explicit. The author is an American biochemist working in London who has long experience of writing popular material through being a correspondent of "Science Service", the American scientific news agency. One is impressed by the tremendous range of facts which he has digested and presented in a most readable form. The occasional Americanisms in the text may upset some, but it would be a pity for anyone to be irritated out of reading the book because of this; they are in fact nothing more than the kind of colloquialisms which add so much to the vividness of popular writing. The book does not ignore the social relations of the subject, but Dr. Feinberg does not allow these aspects to divert him from his main purpose of setting down the scientific facts intelligibly and in their proper perspective. He has achieved a high standard of accuracy, and all round the book is to be recommended as one of the best in its category.

Across the Space Frontier edited by Cornelius Ryan. With a foreword by Sir Harold Spencer Jones, the Astronomer Royal (*London, Sidgwick & Jackson, 1952, 147 pp., 21s.*)

There is now a large literature about space travel, and to judge from the expensive production and art work which goes into so many books on the subject there is evidently a big and enthusiastic readership for it. Moreover, there is nothing perfunctory about the style of writing or of illustration in these books, the enthusiasm of their readers is probably to a large extent a reflection of the enthusiasm of the authors.

This book is no exception. It originated as a symposium which appeared in *Collier's*, the popular American magazine, and the various articles composing it are by men well known in interplanetary circles. After saying that they include Prof. Joseph Kaplan, Wernher von Braun, Dr. F. L. Whipple and Willy Ley, one needs scarcely add any further recommendation, apart from mentioning that the coloured plates are perfect examples of the outstanding art work which seems to characterise the best books of this type.

Rocket Propulsion by Eric Burgess (*London, Chapman & Hall, 1952, 233 pp., 21s.*)

THIS book, which gives a readable and reliable account of the theory of rocket propulsion, is a tribute to the tremendous enthusiasm of the author for his subject. Like most of the early members of the British Interplanetary Society Mr. Burgess is an amateur scientist with no special technical training or practical experience of rocket research. Yet he has obviously devoted a great deal of his time to a study of the chemistry, physics and mathematics involved in rocket design.

The author's forecasts about space travel make entertaining reading, but his views on the future of the rocket in war are not so acceptable. Few military scientists will agree with such statements as this: "Radio equipment can now be built that will permit long range rockets to be so controlled in flight that they will have an accuracy within 10 yards for each hundred miles of range" . . . "A first surprise attack will bring absolute victory to the belligerent nation."

This passage, which comes at the end of a detailed analysis of what would be needed for a journey to the moon, is pure "Beachcomber": "A general repair kit and a medicine chest would also be required. In order to prevent boredom during the long voyage it is suggested that a pack of playing cards be taken."

An Explaining and Pronouncing Dictionary of Scientific and Technical Words by W. E. Flood and Michael West (*London, Longmans, Green & Co., 1952, 397 pp., 12s. 6d.*)

It is tempting for a reviewer, when faced with a book like this, to become severely academic and start to judge definitions in detail according to criteria austerely set. Criticism of this sort can be made of any science dictionary whatever, past and present. No such dictionary is comprehensive; no such dictionary is perfectly up to date. The present book is no exception.

It is handy and compact and full of explanatory line illustrations. It has 10,000 terms covering 50 subjects. The pronunciation is indicated by a phonetic method. Moreover, and how important it is, the book is cheap.

The authors laid down six rules to be obeyed and have printed them at the beginning. This is a courageous thing to do, and very risky, for it gives every would-be critic a chance to wield the axe. As the book is intended to be clear to a person who knows little or nothing about the particular subject the explaining vocabulary is kept small—about 200 words. This statement of the number of words in the vocabulary makes one think at once of basic English. Are the authors making a sporting challenge to the organisers of this system?

It is an attractively produced book, good value for the money. Some definitions are not informative enough; some are so much so that the definition shades into explanation more suited to an encyclopaedia. Yet this is the best of the *cheap* science dictionaries produced in the past several years. No school library can afford to be without it now that the most comprehensive of all such British dictionaries has been unrevised for so many years.

C. L. BOLTZ

Westminster Hospital 1719–1948 by John Langdon-Davies (*London, John Murray, 1952, 274 pp., 21s.*)

IN the last century science has revolutionised medical practice, and this book has an interest for DISCOVERY readers because it gives a vivid account of several of the major developments involved in that revolution. The section dealing with the great advance in surgery which followed the introduction of anaesthetics and antiseptic technique is particularly effective, the author weaving together most skilfully individual case histories to form a clear pattern of medical progress. The volume as a whole will appeal to all those interested in social history.

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